# Atlantic Richfield Company

1290037

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January 31, 2014

Mr. Steven Way
On-Scene Coordinator
Emergency Response Program (8EPR-SA)
U.S. EPA, Region 8
1595 Wynkoop Street
Denver, CO 80202-1129

**RE: Final Design Report**
**St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study**
**Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01**
**Dolores County, Colorado**

Dear Mr. Way:

On behalf of Atlantic Richfield Company (Atlantic Richfield), please find enclosed the *St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Final Design Report* (Report) prepared for the Rico-Argentine Mine Site (site). This Report is being submitted to the United States Environmental Protection Agency, Region 8 (U.S. EPA) to document the design rationale for the St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Unified Design (Unified Design) for constructing a demonstration-scale passive treatment system to evaluate the treatability of mine water discharging from the St. Louis Tunnel. The Unified Design was submitted to the U.S. EPA on December 31, 2013, pursuant to the requirements in Task F – Water Treatment System Analysis and Design / Subtask F2 – Treatment System Conceptual Designs and Additional Investigations of the Remedial Action Work Plan accompanying the Unilateral Administrative Order for Removal Action, Rico-Argentine Site, Dolores County, U.S. EPA Region 8, dated March 9, 2011 (Docket No. CERCLA-08-2011-0005).

A revised Work Plan describing Atlantic Richfield's plans for constructing the wetland demonstration Unified Design, including a revised Performance Monitoring Plan, will be submitted to the U.S. EPA by March 31, 2014.

If you have any questions regarding this Work Plan, please feel free to contact me at (714) 228-6770 or via e-mail at Anthony.Brown@bp.com.

Sincerely,

Anthony R. Brown

Tony Brown
Project Manager Mining
Atlantic Richfield Company

Enclosure: *St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Final Design Report*

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# ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION TREATABILITY STUDY FINAL DESIGN REPORT

**Rico-Argentine Mine Site – Rico Tunnels**
**Operable Unit OU01**
**Dolores County, Colorado**

*Prepared for:*
**Atlantic Richfield**
**La Palma, California**

*Prepared by:*
**AMEC Environment & Infrastructure, Inc.**
**Rancho Cordova, California**

January 2014

Project SA11161340

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## TABLE



## ATTACHMENT

## ABBREVIATIONS

| | |
|---|---|
| AEEC | American Environmental and Engineering Consultants, LLC |
| AFB | Gunderboom Inc. Aquatic Filter Barrier™ system |
| Agridrain | Agri Drain Corporation Inline Water Level Control Structure™ |
| AMEC | AMEC Environment & Infrastructure, Inc. |
| amsl | above mean sea level |
| APS | Applied Polymer Solutions |
| Atlantic Richfield | Atlantic Richfield Company |
| biotreatment cell | anaerobic vertical flow wetland |
| BOD | biochemical oxygen demand |
| BP | British Petroleum |
| cm | centimeter |
| cm/sec | centimeter per second |
| DO | dissolved oxygen |
| FDR | Final Design Report |
| ft | foot |
| $ft^2$ | square foot |
| $ft^3$ | cubic foot |
| ft/d | foot per day |
| ft/ft | foot per foot |
| ft/min | foot per minute |
| ft/s | foot per second |
| g/d | gram per day |
| $g/m^2/d$ | gram per square meter per day |
| gal | gallon |
| GMS | Groundwater Modeling System |
| gpm | gallon per minute |
| Gunderboom | Gunderboom Incorporated |
| H:V | horizontal to vertical |
| $H_2S$ | hydrogen sulfide gas |
| HDPE | high-density polyethylene |
| hr | hour |
| HRT | hydraulic residence time |
| HSSE | Health, Safety, Security, and Environment |
| HSSF | horizontal subsurface flow |
| HWTT | horizontal wetland treatment train |
| LF | linear foot |
| m | meter |
| $m^2$ | square meter |
| mg/L | milligram per liter |
| ORP | oxidation reduction potential |
| PFD | personal floatation device |
| PPE | personal protective equipment |
| PVC | polyvinyl chloride |
| RMC | Resource and Environmental Management Consultants, Inc. |
| SB No. 1 | Settling Basin Number 1 |
| SB No. 2 | Settling Basin Number 2 |

## ABBREVIATIONS
## (CONTINUED)

| | |
|---|---|
| SEC | specific electrical conductance |
| SF | surface flow |
| site | Rico-Argentine Mine Site |
| sonde | multi-parameter water quality sonde |
| SRB | sulfate-reducing bacteria |
| TSS | total suspended solids |
| U.S. EPA | United States Environmental Protection Agency, Region 8 |
| VWTT | vertical wetland treatment train |
| W | watts |
| wetland demonstration | St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study |
| wetland pilot test | St. Louis Tunnel Discharge Constructed Wetland Pilot Scale Test |
| 517 Shaft Injection Test | St. Louis Tunnel Discharge Source Mine Water Treatability Study |
| ° | friction angle |
| °C | degree Celsius |
| °F | degree Fahrenheit |
| > | greater than |
| ≥ | greater than or equal to |
| < | less than |
| ≤ | less than or equal to |
| µg/L | microgram per liter |
| µM/d | micromole per day |
| % | percent |
| ± | plus or minus |

# ST. LOUIS TUNNEL DISCHARGE CONSTRUCTED WETLAND DEMONSTRATION TREATABILITY STUDY FINAL DESIGN REPORT

Rico-Argentine Mine Site – Rico Tunnels
Operable Unit OU01
Dolores County, Colorado

## 1.0 INTRODUCTION

This *Final Design Report* (FDR) has been compiled by AMEC Environment & Infrastructure, Inc. (AMEC), with input from Resource and Environmental Management Consultants, Inc. (RMC) and American Environmental and Engineering Consultants, LLC (AEEC), on behalf of Atlantic Richfield Company (Atlantic Richfield), to document the design rationale for the St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study (wetland demonstration) Unified Design for construction of a demonstration-scale passive treatment system to evaluate the treatability of mine water discharging from the St. Louis Tunnel at the Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01, Dolores County, Colorado (site). The wetland demonstration design previously described in the *St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Work Plan Revision 1* (Work Plan; Atlantic Richfield, 2013) has been revised to incorporate two, independent, constructed wetland treatment trains. The Horizontal Wetland Treatment Train (HWTT) will include a settling basin (SB No. 1) for removal of suspended solids, followed in series by a surface flow wetland, an anaerobic horizontal subsurface flow (HSSF) wetland, an aeration channel, and an aerobic rock drain. The Vertical Wetland Treatment Train (VWTT) will include a settling basin (SB No. 2) followed in series by an anaerobic vertical flow wetland (biotreatment cell) and an aeration cascade. Both the HWTT and the VWTT will incorporate a telemetry system to enable remote monitoring of key elements of the wetland demonstration.

The wetland demonstration design has been developed pursuant to the Unilateral Administrative Order for Removal Action (UAO), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Docket No. 08-20011-0005, effective March 23, 2011 (UAO; United States Environmental Protection Agency [U.S. EPA], 2011a), and the associated Removal Action Work Plan (RAWP), dated March 9, 2011 (U.S. EPA, 2011b), Subtask F2, which requires the completion of treatment system conceptual designs and additional investigations to compare alternatives and support water treatment system designs.

This FDR describes the design intent and features of the HWTT and VWTT. Incorporated into this FDR as an addendum is the final design report describing the telemetry system (Attachment A). Section 2 of this FDR describes the wetland demonstration objectives. Section 3 describes the generalized basis for the wetland demonstration design, as well as features that are common to both treatment trains. Specific design criteria for the HWTT and the VWTT are discussed in Sections 4 and 5, respectively. Section 6 provides a discussion of major health, safety, security, and environment (HSSE) concerns and the engineering controls incorporated into the wetland demonstration design to address those concerns. References are provided in Section 7.

## 2.0 WETLAND DEMONSTRATION OBJECTIVES

The suitability of constructed wetland technologies for treatment of mine discharge has been reported in technical literature and specifically for this site in previous bench- and pilot-scale studies (MWH, 2013; AMEC, 2013b). The wetland demonstration will be used to further evaluate the viability of constructed wetlands to passively reduce metals concentrations in the St. Louis Tunnel discharge. The results of the wetland demonstration will be reviewed to evaluate the potential of full-scale implementation of constructed wetland technology as a treatment remedy.

The wetland demonstration will provide information in the following areas.

- Impact of flow rate on metals removal efficiency (i.e., system performance)
- Limitations and impacts of size and orientation of the constructed wetland basins on system performance
- Effects of heat loss on system performance
- Treatment train hydraulic longevity
- Pre- and post-treatment requirements
- Formation and release of bacteriological hydrogen sulfide ($H_2S$) gas
- Fouling and clogging of the system
- Operations and maintenance requirements
- Efficacy of remote data acquisition via a telemetry system

Several of these objectives have ramifications on the design of a final remedy. Among the most critical of these is the effect of heat loss on system performance. Conservation of heat in the

St. Louis Tunnel discharge is essential to sustaining biological processes and to full-scale operation and maintenance of a constructed wetland.

Another critical issue surrounding the wetland demonstration is the formation and release of $H_2S$ gas. Both the HSSF and vertical flow wetlands will use anaerobic bacteriological activity to convert dissolved metals into metal sulfides. Microbes will produce $H_2S$ as a by-product of this conversion, which then will be released from solution downstream of the wetlands. At elevated concentrations, $H_2S$ could pose health and safety concerns. At low concentrations (i.e., in the range of several parts per million), the gas could pose a public nuisance, as $H_2S$ produces a "rotten egg" smell that can be aesthetically undesirable. The release of $H_2S$ gas from solution to the atmosphere will be monitored during the wetland demonstration. Local airborne concentrations, engineering controls, and mitigations of $H_2S$ gas will be reviewed and assessed for full-scale implementation of a constructed wetland.

Similarly, the project will provide data that can be used to evaluate the expected life of each unit process, including an assessment of clogging and plugging at the inlet and outlet of each unit process. Some degree of clogging and plugging is anticipated to occur as a result of material settlement, deposition, and/or biofouling. Sludge accumulation and changes in hydraulic conductivity over time will be evaluated, and maintenance activities that potentially could prolong the operational lives of the unit processes will be identified and assessed.

## 3.0 COMMON DESIGN BASIS AND FEATURES

The primary objective of the wetland demonstration is to remove particulate iron and dissolved manganese, cadmium, and zinc present in the St. Louis Tunnel discharge to concentrations that are below regulatory discharge limits in a manner that is cost effective, robust, and sustainable. The wetland demonstration design includes specific features that can be used to provide data for full-scale design of a constructed wetland, should this technology be selected for full-scale implementation. Key operating parameters for the wetland demonstration design are provided in the following table.

**Wetland Demonstration Key Operating Parameters**

| | |
|---|---|
| Planned construction period | April – June 2014 |
| Planned start-up date | June 30, 2014 |
| Design flow rate (gpm) | 30 |
| Range of flow rate for demonstration (gpm) | 10 to 50 |
| Influent water temperature (degrees Celsius [°C] / degrees Fahrenheit [°F]) | 6°C to 21°C / 43°F to 70°F |
| Target treatment compounds | iron, suspended solids, cadmium, zinc, manganese |
| Planned test duration (years) | 1 |

The wetland demonstration is anticipated to last at least one year to allow for an assessment of performance during seasons. However, the test period may be extended for a longer duration, or the various unit processes may be incorporated into a final site remedy. Modifications to the wetland demonstration implementation schedule will be subject to approval by the U.S. EPA.

## 3.1 St. Louis Tunnel Discharge Hydrograph and Water Diversion

Flow rates recorded for the St. Louis Tunnel discharge between May 2011 and October 2013 ranged from 491 gpm to 870 gpm (Table 1). The flow rate from the St. Louis Tunnel is directly impacted by local conditions; flow rates measured during 2011 and 2012 reflected dry conditions.

Analyses of flow data from the 1970s and 1980s suggest that the St. Louis Tunnel discharge flow rate may have occasionally exceeded 1,000 gpm. It is pertinent to note that in August 1995, a flow rate of approximately 2,200 gpm was recorded (Paser, 1996). Since that time, no flow rate measurements have exceeded 1,000 gpm for the St. Louis Tunnel discharge.

A diversion structure incorporating existing culverts and pond transfer hydraulics is designed to direct a slipstream of water from the St. Louis Tunnel discharge to the wetland demonstration treatment trains. The flow diversion structure will be installed approximately 30 feet downstream of the Parshall flume at existing monitoring location DR-3. Currently, water from the St. Louis Tunnel flows through the DR-3 flume and then is directed to either Pond 15 or Pond 18. For the wetland demonstration, water will be conveyed along the Pond 18 diversion pathway into a second flow diversion structure, which then will divert water into three pipes. Two pipes, designed to transport flows up to 50 gpm, will convey water into the HWTT and VWTT. Excess water will flow through a new, 18-inch pipe to Pond 18.

### 3.2 WETLAND DEMONSTRATION SYSTEM FLOWS

As described in the *St. Louis Tunnel Discharge Constructed Wetland Pilot Scale Test Completion Report* (AMEC, 2013b), a pilot-scale constructed wetland with a maximum influent flow rate of 6 gpm was operated at the site during late 2012 and throughout 2013. Pilot-scale systems typically can be scaled up by an order of magnitude to demonstration-scale systems. Therefore, the wetland demonstration is designed with a target flow rate of 30 gpm and variable flow rates from 10 gpm to 50 gpm. Should the wetland demonstration prove successful in achieving passive removal of metals from the St. Louis Tunnel discharge, a full-scale constructed wetland, treating approximately 1,000 gpm,[1] could be designed using the lessons learned from the wetland demonstration. If a full-scale 1,000-gpm wetland is pursued, it likely will be constructed to consist of several smaller treatment trains, operating in parallel, to aid in operations and maintenance in the future. This modular approach would allow for a portion of the system to be removed from service for cleaning, repairs, or renovation, while the remaining system components would continue to operate. With this approach, treatment of the discharge would never be interrupted fully.

One of the wetland demonstration objectives is to push each unit process to chemical breakthrough in order to test and then optimize system hydraulics, construction materials/treatment media, and treatment capacity. The HWTT and VWTT have been designed targeting a 30-gpm flow rate for optimal metals removal. Flow rates ranging from 10 gpm to 50 gpm will be tested to collect performance data at various flow rates; seasonal flow rate fluctuations are expected for a full-scale system. Hydraulic breakthrough is expected at a flow rate between 30 gpm and 50 gpm. Operating each treatment train at its maximum hydraulic capacity will help determine the hydraulic residence time (HRT) for each unit process and allow for an evaluation of treatment performance as a function of HRT.

### 3.3 WATER QUALITY AND MONITORING

The wetland demonstration will be constructed approximately 500 feet down-gradient of the St. Louis Tunnel adit. Comparatively, the wetland pilot test was located within the Pond 9 footprint, approximately 2,000 feet down-gradient of the adit through the St. Louis Ponds system. The shortened transit distance of the St. Louis Tunnel discharge to the wetland demonstration is expected to result in different influent water quality in comparison to that of the wetland pilot test.

[1] Development of a full-scale design flow rate will be conducted separately and will require approval from the U.S. EPA.

Water quality monitoring and periodic sampling will be conducted during the wetland demonstration to quantify system efficacy and identify treatment performance variations between the pilot-scale wetland and each of the wetland demonstration treatment trains. Multi-parameter water quality sondes (sondes) will be deployed at the influent and effluent of each unit process of the HWTT and VWTT. The sondes will be equipped with probes to measure the following parameters.

- pH
- Specific electrical conductance (SEC)
- Temperature
- Oxidation reduction potential (ORP)
- DO
- Turbidity (at select locations only)

Deployment of data-logging sondes will allow water quality data to be monitored periodically while requiring minimal site visits. In addition, select monitoring locations will be connected to a telemetry system to allow remote monitoring for signs of system upsets that could indicate a need for personnel to mobilize to the site. This telemetry system is described further in Attachment A.

### 3.4 WATER TEMPERATURE

The wetland demonstration relies on bacteriological activity for the reduction in cadmium, zinc, and manganese concentrations. Microbial activity and degradation of organic carbon are temperature sensitive in that activity decreases in relation to decreasing temperature. Organic matter decomposition slows between approximately 8°C and 12°C (46°F and 53°F) and practically ceases at 4°C (39°F). Temperatures between 10°C and 15°C (50°F and 59°F) are considered to be acceptable for biological manganese oxidation and sulfate reduction, while “warm temperatures” between 15°C and 20°C (59°F and 68°F) are preferred (Arnosti et al., 2003; Kristensen et al., 1995; Knoblauch and Jorgensen, 1999). Therefore, water temperature is a critical operating parameter for biological activity in the HSSF wetland, the VWTT biotreatment cell, and the HWTT rock drain.

Water temperatures from the St. Louis Tunnel discharge have been observed to range from approximately 6°C to 21°C (43°F to 70°F) at the DR-3 surface water monitoring location. As described in Section 3.3, the wetland demonstration will be constructed approximately

1,500 feet closer to the St. Louis Tunnel adit than the pilot-scale wetland, with the diversion located approximately 30 feet downstream from existing monitoring location DR-3. Based upon the proximity of the wetland to the St. Louis Tunnel adit, the temperature-related issues experienced in the wetland pilot test are not anticipated to be present in the wetland demonstration. The wetland demonstration treatment trains will benefit from the proximity to the elevated water temperature of the St. Louis Tunnel adit, without the addition of an external heat source, during the winter months.

Water temperatures at the inlets and outlets of each HWTT and VWTT unit process will be monitored using sondes. Data collected will be used to assess the effects of water temperatures and seasonal variations in treatment performance. In addition, matrix temperature profile probes will be installed in the HSSF wetland and the aerobic rock drain to assess changes in temperature with media depth. Data collected using the temperature profile probes will be correlated with water temperatures measured by the sondes and ambient air temperatures, as reported by the Scotch Creek SNOTEL site (NRCS, 2013).

### 3.5 GROUNDWATER PROFILE

The wetland demonstration was designed to prevent interaction with groundwater in order to better understand the processes occurring within each unit process. Groundwater profiles under the proposed treatment train footprints were developed using Groundwater Modeling System (GMS) software in order to identify possible surface water / groundwater interactions. Using the GMS, potentiometric surfaces were mapped based on available historic groundwater elevation data. This data was compared to historic annual discharge data for the Dolores River and historic precipitation data to determine the anticipated groundwater profile for a "wet" or high flow year.

Based on the available groundwater level data set covering the period from 2002 to 2013, calendar year 2005 was selected as the representative year for a high (i.e., shallow) groundwater profile. When the 2005 groundwater (i.e., potentiometric) surface was compared to proposed design elevations, it was determined that the proposed excavation depths would not intersect the estimated high groundwater profile elevations. Based on this information, it is unlikely that groundwater at the site will interfere with the wetland demonstration. It is not expected that unit process liners will be subject to groundwater-induced damage, such as "floating." Therefore, minimum ballast requirements to counteract liner floating are not necessary.

### 3.6 GEOMEMBRANE DESIGN

Assumptions about subgrade conditions (provided below) were made based on previous geotechnical investigations and field observations during autumn 2013 wetland demonstration construction activities. Based on these assumptions, and in order to minimize flow losses due to leakage through subgrade materials, a single, 60 mil, high-density polyethylene (HDPE) geomembrane will be installed in each of the HWTT and VWTT unit processes. The geomembrane will retain liquid within each unit process, prevent the possible intrusion of groundwater, and aid in establishing the HRTs of the unit processes. A minimum 60 mil geomembrane thickness was recommended, per U.S. EPA guidance for solid waste disposal facilities (U.S. EPA, 1995).

The geomembrane is anticipated to experience minimal settlement. Subgrade condition assumptions are provided in the table below.

**Subgrade Condition Assumptions**

| | |
|---|---|
| Classification of subgrade soil | sandy gravel |
| Thickness of clayey or silty soil | zero |
| Permeability of subgrade soil | high for sandy gravel |
| Largest size of rock in subgrade soil | 3 inches – angular<br>6 inches – round to sub-round |
| Moisture content (percent [%]) | 10 to 20 |
| In situ unit weight (pounds per cubic foot) | 125 |
| California Bearing Ratio | 10 to 40 |
| Effective friction angle of subgrade soil | 30° to 40° |
| Consolidation characteristic of subgrade soil | none for sandy gravel |
| Highest estimated groundwater elevation (feet above mean sea level [ft amsl]) | 8825.00 |
| Lowest subgrade surface elevation (ft amsl) | 8826.14 |

Some areas within the selected wetland demonstration area contain muck and receive flows from the St. Louis Tunnel discharge channel prior to discharging to Pond 18. Construction in these areas may require extensive dewatering, excavation to a stable bottom, and stabilization with clean, imported, structural fill. Conversely, geotextile may be installed, below the geomembrane, to reinforce the subgrade in wet areas. Technical specifications were prepared as part of the original construction documents (AMEC, 2013a) to address subgrade preparation and geotextile placement. The subgrade will be shaped and fill will be placed, graded, and compacted per the specifications.

### 3.7 Flow Rate Monitoring

Influent and effluent flow monitoring will be conducted downstream of the St. Louis Tunnel discharge influent flow diversion structure and at the outlets downstream of the HWTT and VWTT. Flow monitoring will be performed using two-inch diameter, electromagnetic flow meters meeting the specifications provided below. All flow meters will have data-logging capabilities. Flow meters will be installed in insulated, HDPE underground vaults and will be capable of operating at fluid and ambient air temperatures as low as -20°C (-4°F).

**Two-Inch Diameter Electromagnetic Flow Meter Specifications**

| | |
|---|---|
| Flow range (gpm) | 3 to 311 |
| Accuracy (%) | ±0.2 (±0.5 for velocities ≥1.64 feet per second [ft/s]) |

Influent and effluent flowmeters will be connected to the telemetry system to allow operators to evaluate potential losses through the treatment trains and assess if there are operational issues or failures (in the event that influent flow rates do not equal effluent flow rates) that warrant unanticipated site visits for troubleshooting. The telemetry system is further described in Attachment A.

## 4.0 HORIZONTAL WETLAND TREATMENT TRAIN

The HWTT unit processes were designed based on the results of the wetland pilot test (AMEC, 2013b), which demonstrated that constructed wetland technology is a feasible approach to treating water discharging from the St. Louis Tunnel. The design features and unit operations included in the HWTT were specifically selected to account for influent water quality conditions and to accommodate those conditions that were believed to create fouling or upset conditions in the pilot-scale wetland (AMEC, 2013b).

The HWTT will consist of SB No. 1 connected in series to a surface flow (SF) wetland, anaerobic HSSF wetland, aeration channel, and aerobic rock drain. All unit processes will be located in ponds lined with 60 mil HDPE. The influent will consist of a slipstream of water from the St. Louis Tunnel discharge channel, piped from the existing flow diversion point near the existing DR-3 surface water sampling location (Section 3.1). Effluent from the rock drain will flow into the northern end of Pond 18.

Operational data obtained from the HWTT will provide design information that would be required for construction of a full-scale wetland treatment system at the site. The inclusion of specific unit processes, and the order in which the unit operations were designed, will address the high suspended solids concentrations in the St. Louis Tunnel water and promote removal of the dissolved target treatment compounds. The following sections describe the design features and considerations for each of the HWTT unit processes.

## 4.1 HYDRAULIC PROFILE AND CONTROLS

The pilot-scale wetland was designed and constructed such that the system was gravity fed and driven by the hydraulic head between the inlet flow control box water level and the wetland outlet water level. Rock drain and wetland cell subgrades were not sloped, and the outfall was located in a fixed position near the top of the wetland cell matrix, providing little flexibility in the hydraulic operation of the system.

The HWTT will be governed by the hydraulic head available at the flow diversion box. In contrast to the pilot-scale wetland, the HWTT will be provided with hydraulic control structures that may be used to vary the water levels or depths and thus the HRTs of each unit process. The variable depth outlets will be utilized to provide flexibility in the hydraulic operation of the system. Additionally, the matrix surface and subgrade in each unit process will be sloped to encourage uniform flow at all depths at the target flow rate.

The HSSF wetland matrix is designed to provide hydraulic capacity for flows ranging from 10 gpm to 50 gpm. Based on the wetland pilot test results and the modified wetland demonstration matrix composition, the anticipated effective matrix porosity will range from approximately 25% to 33%; hydraulic conductivity is anticipated to range from approximately 1,500 feet per day (ft/d) to 6,200 ft/d (0.5 centimeter per second [cm/sec] to 2.2 cm/sec). The subgrade will be sloped to provide uniform flow at all depths along the flowpath at the target flow rate. The hydraulic gradient of the HSSF wetland is designed to provide hydraulic capacity for hydraulic gradients ranging from 0.0012 foot per foot (ft/ft) to 0.0241 ft/ft. The following elevations are planned for the HWTT.

**HWTT Design Elevations**

| Item | SB No. 1 | SF Wetland | HSSF Wetland | Aeration Channel | Rock Drain |
|---|---|---|---|---|---|
| Bottom elevation(s) (ft amsl; inlet end / outlet end) | 8833.70 | 8836.35 / 8836.15 | 8831.79 / 8831.46 | 8830.61 / 8830.44 | 8826.80 / 8826.14 |
| Depth (ft) | 6.0 | 2.0 | 4.8 | 2.0 | 3.44 |
| Matrix/wetted side slope (horizontal to vertical [H:V]) | 1:1 to 2.25:1 | 3:1 | 3:1 | 1:1 to 3:1 | 3:1 |
| Freeboard (ft) | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Top of freeboard elevation (ft amsl) | 8840.70 | 8839.35 | 8837.59 | 8833.61 | 8831.30 |
| Freeboard side slope (H:V) | 2.25:1 | 3:1 | 3:1 | 1:1 to 3:1 | 3:1 |

## 4.2 SETTLING BASIN NUMBER 1

*Purpose:* Remove suspended solids and particulate and colloidal iron from wetland demonstration influent.

*Target Treatment Compounds:* Total suspended solids (TSS) and total iron

*Effluent Treatment Goals:*[2] Less than (<) 10 milligrams per liter (mg/L) and <3 mg/L, respectively

Based upon field observations and analytical testing results from the wetland pilot test, it was determined that particulate loading impaired the performance of the rock drain. Particulate iron was observed to armor the pilot-scale rock drain surfaces and interfere with deposition of manganese oxide. The presence of suspended solids also may have contributed to clogging and subsequent loss of hydraulic conductivity in the pilot-scale wetland cell as particles were deposited in and filtered by the wetland cell matrix material.

The particulate load in the St. Louis Tunnel discharge must be addressed for the wetland demonstration to be successful. Concentrations of TSS present in the St. Louis Tunnel discharge typically range from <5.0 mg/L to approximately 50 mg/L (AECI, 2011 to 2013). The negative impacts of particulates on rock drain manganese removal and the hydraulic conductivity of the HSSF wetland matrix require that TSS and iron concentrations be decreased prior to flow entering the HSSF wetland.

[2] The Effluent Treatment Goals are not intended to be fixed targets. Rather, they represent the target concentrations to be achieved by the unit process.

For the HWTT, SB No. 1 will be used as a treatment step to remove TSS, including particulate and colloidal iron, from the HWTT influent. A coagulant or flocculant solution will be injected into the bulk solution at a point upstream of SB No. 1 to enhance the removal of fine particulates and colloids. Additional methodologies also may be tested to enhance removal of finer particles, possibly including the use of flocculant logs from Applied Polymer Systems (APS) or installation of a Gunderboom Incorporated (Gunderboom) Aquatic Filter Barrier™ system (AFB).

The settling basin will consist of a pond-like structure with a length to width ratio of 3.4:1, designed to promote gravitational settling to remove TSS and total iron concentrations to <10 mg/L and <3 mg/L, respectively. Although complete removal of TSS and iron to non-detectable concentrations would be ideal, these effluent treatment goals were selected to balance TSS and iron removal with settling basin size requirements and associated heat loss. Design criteria for SB No. 1 are provided in the table below.

**Settling Basin No. 1 Design Criteria**

| | |
|---|---|
| Design flow rate, testing range (gpm) | 30, 10 to 50 |
| Width (ft) | 22.5 |
| Length (ft) | 76.5 |
| Surface area (square feet [$ft^2$]) | 1,721 |
| Total depth (ft) | 7.0 |
| Depth of water (ft) | 6.0 |
| Average side slope (H:V) | 2.25:1, then 1:1 |
| Longitudinal bed gradient (%) | 0 |
| Volume (cubic feet [$ft^3$] / gallons [gal]) | 4,430 / 33,140 |
| HRT for 30 gpm at start-up (hours [hr]) | 18 |
| Assumed volume of sludge per year ($ft^3$ / gal) | 1,900 / 14,500 |
| HRT for 30 gpm after one year (hr) | 10 |

The following assumptions and considerations were incorporated into the SB No. 1 design.

- **Particle settling velocity** – The basin was originally sized for a particle settling velocity of 0.02 foot per minute (ft/min), a conservative settling velocity for flocculated particulates, based on literature review. The settling basin size was increased to allow for constructability and increased sludge accumulation. With a surface area of 1,721 square feet, the surface-loading rate is 0.002 ft/min, an order of magnitude less than the settling velocity.

- **Flow control/hydraulics** – The water level within SB No. 1 has approximately one foot of variation and will be controlled by a downstream inline flow control structure.

- **Geomembrane and matrix** – SB No. 1 will be lined but will not be filled with media. The surface of the settling basin will be covered with four-inch diameter floating HDPE balls that will serve to retain heat in the basin during periods of cold weather.

- **Sludge accumulation** – The sludge volume accumulation is estimated to be approximately 1,900 cubic feet over a one-year period, based on assumed solids removal of 9 mg/L, a sludge density of 8.34 pounds per gallon, and a solids concentration of 1.0%. It is anticipated that, over time, the sludge density will increase, thereby decreasing the sludge volume.

The following subsections describe key elements of SB No. 1 and the assumptions related to their design.

### 4.2.1 Inlet Hydraulic Control Structure

The inlet to SB No. 1 will consist of a 3-inch pipe with a tee to begin distributing the inflow along the width of the settling basin.

### 4.2.2 Coagulant

Finely divided particulate and colloidal iron will not settle out of solution by gravitational means in an open pond system. Therefore, a coagulant will be injected into SB No. 1 to enhance the removal and settling of fine TSS and colloidal iron by coagulating, increasing particle size, and increasing settling velocity. The use of flocculants/ coagulants is well understood for removing TSS and iron from solutions; therefore, a coagulant will be injected to SB No. 1 immediately upon system start-up.

In 2013, laboratory screening was performed to test the efficacy of multiple coagulants and flocculants at removing TSS and iron from the St. Louis Tunnel discharge. ClearTech CTI 4900, an aluminum chlorohydrate coagulant, showed the most favorable results. Based on the laboratory screening results, ClearTech CTI 4900 will be injected into SB No. 1 at a dosing rate up to 15 mg/L. At the 30 gpm design wetland demonstration flow rate, this dosing rate would result in an injection rate of up to 1.7 grams per minute. ClearTech (a Canadian company) provides CTI 4900 for shipment to the U.S. in 1,000-liter totes. At the design injection rate, one tote could supply enough coagulant for four months of use.

The proposed coagulant injection pump is the Blue-White Industries FlexFlo A1N00F-4T peristaltic metering pump. This injection pump is of sufficient size to satisfy demand at the high end of the wetland demonstration design flow range (50 gpm) and has a turndown ratio that will allow for variation in the coagulant dosing injection rate. The pump operating range is from

0.018 liter per hour (L/h) to 0.36 L/h, which provides an operational range between 5 mg/L at 10 gpm (0.02 L/h) and 15 mg/L at 50 gpm (0.3 L/h).

Coagulant will be injected into the HWTT influent via a distribution pipe upstream of SB No. 1. A static mixer with six mixing elements, per the manufacturer's recommendation, will mix the coagulant inside the distribution pipe. The selected mixer is a low pressure loss model, designed to minimize head loss through the unit.

### 4.2.3 Floating Baffle

Short-circuiting can negatively impact effluent concentrations by reducing the HRT. Therefore, a floating baffle will be installed to promote even distribution of water across SB No. 1 and prevent short-circuiting by encouraging more uniform flow. The floating baffle will include a float across the water surface with an impermeable curtain hanging vertically below the float and extending to the sides and bottom of the basin. The impermeable curtain will span the entire width of the basin, perpendicular to the flow direction, and will permit flow to pass through circular openings evenly spaced horizontally across the basin. Higher flow velocity will discourage settling of suspended particles and could re-suspend settled solids. A floating baffle will reduce the water velocity and enhance particle settling.

### 4.2.4 Outlet Hydraulic Control Structures

The SB No. 1 outlet hydraulic control structure will consist of a six-inch diameter perforated pipe connected in series to an Agridrain. The perforated pipe will collect effluent across the entire width of SB No. 1, helping to minimize short-circuiting and reduce exit velocities. The perforated pipe is intended to encourage flow to evenly enter the outlet pipe from a wide area. The larger pipe diameter and numerous perforations will help prevent clogging of the outlet pipe by slimes. Cleanouts located at the ends of the perforated outlet pipe will allow for discharge of entrained air at system start-up and provide access to the effluent pipe for cleaning or maintenance, if necessary. The AgriDrain will be installed downstream of the perforated effluent collection pipe to allow for tailwater hydraulic control of water levels within SB No. 1, which will be adjustable up to 0.75 foot.

### 4.3 SURFACE FLOW WETLAND

*Purpose:* Remove residual suspended solids and particulate and colloidal iron from the SB No. 1 effluent.

*Target Treatment Compounds:* TSS and total iron

*Effluent Treatment Goal:* <10 mg/L and <0.5 mg/L, respectively

The SF wetland will provide an additional unit process for removal of particulate iron and other suspended solids from the St. Louis Tunnel discharge. Located downgradient of SB No. 1, the SF wetland is designed to remove residual iron from an anticipated influent concentration of 3 mg/L to less than 0.5 mg/L, a concentration anticipated not to result in clogging of the downgradient HSSF wetland matrix. To achieve this effluent iron concentration, the SF wetland dimensions were determined based on the iron removal observations reported by Hedin (2008). Design criteria for the SF wetland are provided in the table below. Key design elements and assumptions are discussed in the following subsections.

**SF Wetland Design Criteria**

| | |
|---|---|
| Design flow rate, testing range (gpm) | 30, 10 to 50 |
| Surface area ($ft^2$ / square meter [$m^2$]) | 1,345 / 125 |
| Width (ft / meter [m]) | 25 / 7.6 |
| Length (ft / m) | 54 / 16.4 |
| Side slope (H:V) | 3:1 |
| Longitudinal bed gradient (%) | 0.3 |
| Maximum anticipated influent iron concentration (mg/L) | 3 |
| Target effluent iron concentration (mg/L) | <0.5 |
| Iron removal rate (gram per square meter per day [$g/m^2/d$]; Hedin, 2008) | 4 |
| Iron mass removal through SF Wetland (grams per day [g/d]) | 409 |

#### 4.3.1 Inlet Hydraulic Control Structure

It is desirable for influent to enter the SF wetland uniformly and be distributed evenly. Therefore, a perforated inlet pipe will transport influent across the width of the SF wetland. The perforated pipe will be fitted with a clean-out to enable maintenance of the pipe, which may include releasing air during system start-up and removal of biofilm. The perforated pipe bedding will consist of 3-inch to 6-inch nominal diameter washed, rounded rock in order to evenly distribute flow into the SF wetland.

#### 4.3.2 Topsoil and Organic Media

The SF wetland matrix will consist of topsoil as growing media for sedges, which will be planted throughout the SF wetland. Sedges are intended to remove iron and TSS both physically, by slowing flow velocities and promoting gravitational settling, and biologically, through adsorption and/or absorption of metals through their root structures. Above the topsoil, the operating water depth within the SF wetland will be maintained near one foot. The bottom of the SF wetland will be nearly level (0.3% grade) to ensure even flow across the water surface.

Construction of the HWTT is anticipated to be completed in June 2014, providing the SF wetland with a full growing season for establishment of organic media. Particulate removal in surface flow wetlands improves as the vegetation matures and the layer of detritus within the wetland develops. Published technical literature reports that full removal rates are seen typically within five to eight years after initial operation. Short-term operation of the SF wetland still will provide valuable information regarding heat loss across the unit process, which may affect performance of the downgradient HSSF wetland.

#### 4.3.3 Outlet Hydraulic Control Structure

The SF wetland outlet hydraulic control structure is configured similarly to the inlet structure. A 6-inch diameter perforated pipe will be bedded within 3-inch to 6-inch diameter washed, rounded rock, which will promote flow toward the perforated outlet pipe. The outlet pipe will connect in series to an Agridrain, which will enable tailwater control for depth variations between 0.5 foot and 1.0 foot.

### 4.4 ANAEROBIC HORIZONTAL SUBSURFACE FLOW WETLAND

*Purpose:* Promote the growth of sulfate-reducing bacteria (SRB) in an anaerobic environment and induce biological sulfate reduction for treatment of dissolved cadmium and zinc, present in the St. Louis Tunnel discharge, to form insoluble metal sulfides.

*Target Treatment Compounds:* Cadmium and zinc

*Effluent Treatment Goal:* <0.5 µg/L and <100 µg/L, respectively

The HSSF wetland will be included in the wetland demonstration primarily to remove cadmium and zinc. These metals will be retained in the wetland matrix as insoluble sulfides. The HSSF also is expected to remove other metals present in the St. Louis Tunnel discharge at low concentrations, including copper, iron, lead, and nickel. During the wetland pilot test, the anaerobic HSSF wetland cell was located downstream of the rock drain. However, for the wetland demonstration, the HSSF wetland will be located upstream of the rock drain in order to receive the greatest benefit from the elevated water temperature of the St. Louis Tunnel discharge.

The key design considerations for the HSSF wetland included HRT, matrix media size and composition (which relate to porosity and hydraulic conductivity), lateral water distribution, and inlet and outlet structure clogging mitigation. HSSF wetland design criteria are provided below.

**HSSF Wetland Design Criteria**

| | |
|---|---|
| Design flow rate, testing range (gpm) | 30, 10 to 50 |
| Top width (ft) | 89 |
| Top length (ft) | 66 |
| Basin surface area ($ft^2$) | 5,874 |
| Depth of wetland matrix material (ft) | 4.8 |
| Depth of water (ft) | 3.8 |
| Side slope (H:V) | 3:1 |
| Longitudinal bed gradient (%) | 0.7 |
| Volume of wetland matrix ($ft^3$ / gal) | 18,700 / 140,000 |
| Particle diameter (inch) | 1.0 to 2.0 |
| Porosity of wetland matrix (%) | 33 |
| Pore volume (gal) | 46,200 |
| Hydraulic conductivity (ft/d) | 3,300 |
| HRT at design flow (hr) | 25 |

The following assumptions and considerations were incorporated into the HSSF wetland design.

- At the target flow rate of 30 gpm, modeling has shown the water level is expected to be constant throughout the HSSF wetland at a depth of approximately 3.8 feet.
- The assumed hydraulic conductivity is 3,300 ft/d, including a clogging factor of ten and an estimated porosity of 33%.
- The total matrix depth (4.8 feet) is adequate to accept an influent flow rate of 50 gpm with no short circuiting.
- The operating water surface in the HSSF wetland is expected to be below the surface of the matrix.

- The bottom of the HSSF wetland will have a grade of 0.7% to promote even water flow across its surface.

The following subsections describe key elements of the HSSF wetland and the assumptions related to their design.

### 4.4.1 Inlet Hydraulic Control Structure

Stagnant areas in treatment cells have been identified as partial contributors to poor treatment performance and as areas prone to clogging. Ideally, influent will enter and exit the HSSF wetland uniformly distributed across the matrix. Preventing stagnation can be difficult when attempting to distribute flow from a pipe across a wide area in a short distance. The use of an open trench with a screened opening to the matrix would be an ideal hydraulic solution. However, constructing a deep box would require stout structural reinforcement, and the open water surface would pose a safety hazard and increased heat loss. Therefore, a 6-inch diameter perforated inlet pipe bedded in 3-inch to 6-inch nominal diameter washed, rounded rock will be used to transport influent across the width of the HSSF wetland. The perforated pipe is large enough to perform more as a reservoir than a conduit. This element will be the primary means of lateral flow distribution, enabling influent to flow into the HSSF wetland unimpeded by matrix or other material. The perforated pipe will be fitted with a clean-out to allow for maintenance, including removal of any biofilm that may develop within the pipe.

Hydrogeologic modeling demonstrated that 3-inch to 6-inch diameter rock will provide very high hydraulic conductivity compared to the tighter HSSF wetland matrix. Therefore, the rock bedding will promote vertical distribution in addition to lateral distribution. This simple design allows for ease of construction with common materials, eliminates open water hazards, and minimizes heat loss by promoting subsurface flow conditions through the matrix material.

### 4.4.2 Matrix Material

The HSSF wetland matrix composition is designed to promote microbial activity and induce biological reduction of influent cadmium and zinc to insoluble metal sulfides. The specified matrix materials provide organic sites for colonization by SRB while also ensuring that the matrix is uniformly sized to promote efficient hydraulics and minimize clogging and short-circuiting. Results from the wetland pilot test indicated that the pilot-scale wetland cell matrix experienced clogging, consolidation, and/or loss of permeability, resulting in a reduction in hydraulic conductivity and flow through the wetland cell (AMEC, 2013b). To improve long-term hydraulic performance of the HSSF wetland, the matrix composition will be modified, as presented in the table below. The matrix will be inoculated with SRB from the pilot-scale wetland to promote rapid colonization of the HSSF wetland. Similar to the inoculation rate for the pilot-scale wetland, the ratio of SRB to matrix material for the HSSF wetland will be approximately 1:200.

**HSSF Wetland Matrix Composition (Percentage by Volume)**

| | |
|---|---|
| 1.5-inch to 2.0-inch diameter rounded rock | 60 |
| 1.0-inch to 2.0-inch diameter wood chips | 35 |
| Manure | 4.6 |
| Sulfur prills | 0.38 |
| Liquid fish fertilizer | 0.02 |
| Inoculum to matrix ratio | 1:200 |

The matrix material is sized to promote laminar flow through the HSSF wetland. Uniformity of the material size also allows for maximum interconnected porosity. The HSSF wetland matrix is designed to be clast supported (the matrix composition is 60% rock by volume) to minimize settling and maintain hydraulic conductivity. The specifications for gradation of wood chips and rock size ensure that the HSSF wetland will maintain the targeted hydraulic conductivity more effectively than was observed in the pilot-scale wetland. The sources for these materials will be available in large volumes that also can be supplied for a full-scale system.

### 4.4.3 Vegetation

The HSSF wetland will be planted with cattails (*Typha latifolia*), which ultimately will provide a long-term organic carbon source.[3] Although cattails for the pilot-scale wetland were obtained from an on-site borrow area, cattails for the wetland demonstration will be obtained from nursery stock to better replicate the construction of a full-scale system.

### 4.4.4 Outlet Hydraulic Control Structure

The HSSF wetland outlet hydraulic control structure is configured similarly to the inlet structure. Assuming flow through the HSSF wetland is uniform, the outlet hydraulic control structure will need to capture flow evenly across the width and depth of the wetland. Therefore, a 6-inch diameter perforated pipe will capture flow across the width of the HSSF wetland. The perforated pipe will be bedded within 3-inch to 6-inch diameter washed, rounded rock, which will promote even distribution of flow vertically into the perforated pipe. The perforated pipe will connect to an effluent pipe which will connect in series to an Agridrain, which will also serve as the inlet to the aeration channel. The Agridrain will allow the HSSF wetland outlet water level to be adjusted

[3] Organic carbon will be provided from the release of organic carbon from plant roots as well as the decomposition of detritus in a mature wetland.

from the top of the matrix vertically downward by as much as 3.5 feet. This vertical adjustment will enable operators to fine-tune flow depths in the matrix to promote uniformity throughout the length of the HSSF wetland. The HSSF wetland effluent will remain anoxic until reaching the Agridrain, minimizing biofouling within the outlet piping.

### 4.4.5 Performance Monitoring

Eleven monitoring ports are planned within the HSSF wetland. During periodic monitoring events, water levels and water quality parameters will be measured in all 11 of the HSSF wetland monitoring ports to evaluate changes in water elevations and chemistry and assess potential preferential pathway development. Of the 11 proposed monitoring ports, only two will be used to collect water samples for laboratory analysis. Semi-monthly analytical water sampling activities are anticipated for these two locations. The following briefly describes the rationale for these 11 monitoring ports. In addition to the monitoring ports discussed herein, water quality monitoring and sampling will be performed at the SF wetland effluent to evaluate HSSF wetland influent chemistry. Additional details regarding sampling and monitoring, including analyses and frequencies, will be presented under separate cover in a revised Performance Monitoring Plan.

- Located at the inlet to the HSSF wetland, one monitoring port will be screened in 3-inch to 6-inch nominal diameter rock and used to monitor the inlet water elevation. This data will be used to calculate the hydraulic gradient through the HSSF wetland.

- Three monitoring ports will be screened in the HSSF wetland matrix near the inlet end of the HSSF wetland, and water elevations will be measured to monitor the lateral distribution of water flowing into the matrix from the inlet structure (perforated horizontal flow distribution pipe). Water elevations measured in these monitoring ports will be compared to elevations measured at the inlet. Equalized water elevations would suggest that the inlet flow distribution design facilitates consistent lateral distribution of flow across the width of the HSSF wetland, while any differences in water elevations would suggest that flow paths through the matrix may not be uniform and/or matrix clogging may be occurring at or near the HSSF wetland inlet.

- Three monitoring ports will be screened in the HSSF wetland matrix near the center (longitudinally) of the HSSF wetland, and water elevations will be measured to evaluate hydraulics along the HSSF wetland flow path. Differences in water elevations between the inlet monitoring ports and these central monitoring ports would suggest that the flow path through the matrix is not uniform, which could indicate matrix clogging or non-homogeneity of matrix materials. In addition, water sampling will be performed at one monitoring port located in the center of the HSSF wetland to understand the HSSF wetland process chemistry. Analytical data from this midpoint monitoring port will help assess chemical concentrations along the length of the HSSF wetland, identify changes in HSSF wetland performance as they relate to operational changes (i.e., changes to influent flow rates), and aid in design of a full-scale HSSF wetland. If target constituents (i.e., cadmium and zinc) are detected in the midpoint monitoring port but not at the HSSF wetland outlet, interpolation can be performed to determine the optimal HSSF wetland size at the operating flow rate.

- Three monitoring ports will be screened in the HSSF wetland matrix near the effluent of the HSSF wetland, and water elevations will be measured to monitor the lateral distribution of water flowing from the matrix into the outlet structure. Similar to the inlet, the outlet is designed to uniformly collect flow across the width of the HSSF wetland. Water elevations measured in these monitoring ports will be compared to elevations measured at the other HSSF wetland monitoring ports. Equalized water elevations would suggest that the inlet and outlet flow distribution designs facilitate consistent lateral flow distribution across the width of the HSSF wetland, while any differences in water elevations would suggest that flow paths through the matrix may not be uniform and/or matrix clogging may be occurring at or near the HSSF wetland outlet.

- Located near the HSSF wetland outlet, one effluent monitoring port will be screened in 3-inch to 6-inch diameter rock and will be used to estimate the hydraulic gradient through the HSSF wetland. In addition, this monitoring port has been selected as the effluent sampling location, rather than sampling the inlet to the aeration channel, to minimize worker exposure to $H_2S$ gas. As such, this monitoring port will house a multi-parameter sonde. During the pilot–scale wetland test, substantial sensor fouling due to biofilm and elemental sulfur deposition was observed in the outlet to the wetland cell, where anoxic water became oxidized. It is anticipated that sensor fouling will be minimized by placing a multi-parameter sonde in the effluent monitoring port rather than inside the Agridrain at the inlet to the aeration channel.

It is anticipated that at least three tracer studies will be conducted during the wetland demonstration to evaluate HRTs for the 30 gpm test run. Tracer study results will be used to aid in the approximation of matrix hydraulic conductivity and to evaluate if matrix clogging is occurring. These data also will be used to evaluate if preferential flow pathways exist that may result in short-circuiting, which would negatively affect treatment performance.

Slug testing will be performed in all 11 monitoring ports to identify changes in hydraulic conductivity laterally, along the length of the HSSF wetland, and over time. Slug testing is anticipated to be performed during the HSSF wetland colonization period to estimate the initial matrix hydraulic conductivity, once at the end of the 30 gpm test run to assess changes in matrix hydraulic conductivity, and again at the end of the wetland demonstration to estimate final matrix hydraulic conductivity. Additional hydraulic testing, such as pumping tests, may be performed to dynamically evaluate how the wetland matrix responds to water level changes.

## 4.5 AERATION CHANNEL

*Purpose:* Consume sulfide and biochemical oxygen demand (BOD) and re-oxygenate the anaerobic HSSF wetland effluent prior to flow entering the aerobic rock drain.

*Target Treatment Compounds:* Sulfide, BOD, and DO

*Effluent Treatment Goal:* <0.01 mg/L, <30 mg/L, and greater than (>) 5 mg/L, respectively

An aeration channel is located downstream of the anaerobic HSSF wetland in order to consume effluent sulfide and BOD and increase DO concentrations prior to flow entering the aerobic rock drain. The aeration channel inlet is designed to gradually oxygenate water within an Agridrain, which will oxidize sulfide to elemental sulfur and minimize the release of $H_2S$ gas from solution. The Agridrain structure also will provide hydraulic depth control for the upstream HSSF wetland.

The aeration channel will be constructed of washed rock and will consist of two distinct reaches. The upper reach will comprise a bubbler pool that promotes laminar flow for biological oxidation of sulfide and BOD. Dissolved oxygen is expected to be consumed as fast as it is supplied in this reach, and elemental sulfur is expected to be retained in this deeper portion of the aeration channel. In contrast, the lower reach will be relatively steep and shallow to promote riffling and re-aeration of the water.

The aeration channel is anticipated to release $H_2S$ gas from the HSSF wetland effluent. Design considerations with respect to HSSE are described in Section 6. Aeration channel design criteria are provided below. The following subsections describe key elements of the aeration channel and the assumptions related to their design.

**Aeration Channel Design Criteria**

| | |
|---|---|
| Design flow rate, testing range (gpm) | 30, 10 to 50 |
| Anticipated DO concentration at inlet (mg/L) | 0 |
| Target DO concentration at outlet (mg/L) | >5 |
| Length (ft) | 60 |
| Washed rock nominal diameter (inch) | 3 to 6 |

### 4.5.1 Inlet Hydraulic Control Structure

The inlet to the aeration channel was designed to control water depth in HSSF wetland through the use of removable polyvinyl chloride (PVC) weir slats in an Agridrain and to promote biological oxidation of sulfide to elemental sulfur using slow vertical ascent through media within the Agridrain. The Agridrain's adjustable PVC weir slats allow for up to 3.5 feet of hydraulic depth variability within the SSF wetland. Synthetic trickle media (e.g., Durapac VF48) will provide surface area for growth of biological sulfide oxidizers in the lower four feet of the Agridrain. The media is easily removable, can be cleaned to prevent clogging by accumulated elemental sulfur, and can be replaced as needed. The media will not require inoculation, as sulfide-oxidizing bacteria are ubiquitous in nature and colonies develop rapidly. The HRT within the Agridrain, through the media, is between three minutes and five minutes at 30 gpm, depending on the selected weir height needed for hydraulic control in the HSSF wetland. From the top of the Agridrain, water will drop up to 3.5 feet into the aeration channel bubbler pool.

### 4.5.2 Bubbler Pool

The bubbler pool was designed to promote biological oxidation of residual sulfide, present in the HSSF wetland effluent, to elemental sulfur by sulfide-oxidizing bacteria. Elemental sulfur was a dominant sulfur form in the wetland pilot test (AMEC, 2013b) and also is anticipated to become deposited on the rock matrix comprising this pool.

Luther et al. (2011) demonstrated that under abiotic, metal-free conditions, sulfide has a half-life of approximately 55 days and a removal rate of approximately 0.91 micromole per day (µM/d; 0.03 mg/L/day). In these experiments, the concentration of bisulfide ($HS^-$) decreased from about 3.1 mg/L to about 1.3 mg/L over a period of 140 days. In contrast, in the presence of sulfide-oxidizing bacteria, the sulfide removal rate was approximately 26,200 µM/d (867 mg/L/day), and the concentration of sulfide decreased from about 2.7 mg/L to 0.66 mg/L in approximately 3.3 minutes. Based on the latter removal rate, the bubbler pool was designed to promote biological oxidation of sulfide.

Design criteria for the bubbler pool are provided below. This design minimizes heat loss from exposed surface area while providing solar exposure to allow photosynthesizing biotic oxidizers to colonize the pool.[4] Furthermore, a provision was incorporated into the design for installation of a bubbler in the pool to allow additional oxygen to be transferred into the pool in order to consume BOD, if it is not consumed adequately in the Agridrain and pool without the bubbler.

[4] Both photosynthesizing and non-photosynthesizing sulfide-oxidizing bacteria are anticipated to colonize the bubbler pool naturally.

**Bubbler Pool Design Criteria**

| | |
|---|---|
| Channel bottom width (ft) | 2 |
| Channel top width (ft) | 8 |
| Length (ft) | 31.6 |
| Depth (ft) | 2 |
| Rock depth (inch) | 9 |
| Side slope (H:V) | 1:1 |
| Longitudinal bed gradient (%) | 0 |
| Channel velocity (ft/min) | 0.5 |
| Washed rounded rock nominal diameter (inch) | 3 to 6 |
| HRT at target flow rate (min) | 68 |

### 4.5.3 Rock Channel

Located downgradient of the bubbler pool, the rock channel was designed to increase dissolved oxygen concentrations from near 0 mg/L in the influent to a target minimum of 5 mg/L in the aeration channel effluent. Flow in the rock channel is intended to be fully turbulent to optimize transfer of oxygen along 1.4 feet of channel drop. The target water depth of 1.2 centimeters (cm) was identified for optimal gas transfer, per Younger, Banwart, and Hedin (2002). The relationships for gas transfer utilized to size the rock channel were obtained from Watson, Walters, and Hogan (1998). A surface water 1D HEC-RAS model was used to determine water depths and Froude numbers for design flow rates ranging from 10 gpm to 50 gpm. The rock in this surface-flow reach was sized to be large enough so as not to erode; the rock type was selected to consist of a common material used elsewhere for the wetland demonstration. Design criteria for the bubbler pool are provided below.

**Rock Channel Design Criteria**

| | |
|---|---|
| Channel bottom width (ft) | 2 |
| Channel top width (ft) | 8 |
| Length (ft) | 28.4 |
| Depth (inch) | 9 |
| Rock depth (inch) | 9 |
| Water depth (cm) | 1.2 |
| Side slope (H:V) | 1:1 |
| Longitudinal bed gradient (%) | 5 |
| Channel velocity (ft/min) | 42 |
| HRT at target flow rate (seconds) | 41 |
| Washed rounded rock nominal diameter (inch) | 3 to 6 |

### 4.5.4 Outlet Hydraulic Control Structure

The aeration channel outlet hydraulic control structure was designed to promote settling of suspended solids in order to minimize TSS in the rock drain influent. The aeration channel outlet structure consists of a concrete box fitted with an HDPE grate and frame to screen large debris from the aeration effluent. The outlet of the box is set approximately two feet above the bottom of the box, yielding a HRT of approximately four minutes and allowing large TSS to settle within the box. At the target flow rate of 30 gpm, the water surface in the outlet box will be above the crown of the outlet, thereby minimizing entrainment of floating debris in the rock drain influent. The water surface will be 9 inches below the HDPE grate, allowing for variable water depths within the outlet structure.

## 4.6 AEROBIC ROCK DRAIN

*Purpose:* Promote the growth of manganese-oxidizing bacteria in an aerobic environment to induce biological and chemical oxidation of dissolved manganese, present in the St. Louis Tunnel discharge, and form insoluble manganese oxides.

*Target Treatment Compounds:* Manganese

*Effluent Treatment Goal:* <150 µg/L

The aerobic rock drain (rock drain) will be included in the HWTT to remove dissolved manganese from the St. Louis Tunnel discharge. As discussed in Section 4.4, the HSSF wetland will be located upstream of the wetland demonstration rock drain in order to receive the greatest benefit from the elevated water temperature of the St. Louis Tunnel discharge. The wetland pilot test demonstrated that rock drain performance was not affected by low water temperatures. Therefore, rock drain performance is not anticipated to be affected by cooler water temperatures downstream of the HSSF wetland.

The rock drain will be constructed of angular limestone seeded with manganese-oxidizing microbes. Manganese removal in the rock drain is anticipated to occur by a combination of biological and chemical oxidation. The rock drain material from the pilot-scale wetland will be utilized to inoculate the wetland demonstration rock drain. The inoculum will be mixed with limestone immediately before placement in the rock drain. The key design considerations for the rock drain included HRT and matrix media size (i.e., porosity and hydraulic conductivity). Rock drain design criteria are provided below.

**Rock Drain Design Criteria**

| | |
|---|---|
| Design flow rate, testing range (gpm) | 30, 10 to 50 |
| Width (ft) | 39 |
| Length (ft) | 124 |
| Surface area ($ft^2$) | 4,836 |
| Depth of matrix (ft) | 3.44 |
| Depth of water in rock matrix at 30 gpm (ft) | 2.8 |
| Average side slope (H:V) | 3:1 |
| Longitudinal bed gradient (%) | 0.6 |
| Volume of rock drain matrix ($ft^3$ / gal) | 11,582 / 86,639 |
| Particle diameter (inch) | 1.5 to 2.0 |
| Effective Porosity of rock matrix (%) | 38 assumed,<br>30 to 38 anticipated |
| Pore volume at assumed porosity (gal) | 32,923 |
| Initial hydraulic conductivity (ft/d) | 16,400 |
| HRT at design flow rate and assumed porosity (hr) | 18.3 |

The following assumptions and considerations were incorporated into the rock drain design.

- Optimal manganese removal is expected near 30 gpm. At this flow rate, modeling has shown the water level is expected to be constant throughout the rock drain at a depth of approximately 2.8 feet.

- Assumed hydraulic conductivity of 5,000 meters per day (16,400 ft/d), including a clogging factor of 10 and an estimated porosity of 38%.

- The total matrix depth (3.44 feet) is adequate to accept an influent flow rate of 50 gpm with no short circuiting.

- The operating water surface in the rock drain is expected to be below the surface of the matrix.

- The bottom of the rock drain will have a grade of 0.6% to promote constant water depths along the profile.

The following subsections describe key elements of the rock drain and the assumptions related to their design.

### 4.6.1 Inlet Hydraulic Control Structure

As was described for the HSSF wetland (Section 4.4.1), preventing stagnant flow can be difficult when attempting to distribute water from a pipe across a wide area in a short distance. To mitigate stagnation, a 6-inch diameter perforated inlet pipe bedded in 3-inch to 6-inch nominal diameter washed, rounded rock will transport influent across the width of the rock drain. The perforated pipe will be large enough to serve as a reservoir, promoting lateral flow dispersion. Hydrogeologic modeling indicated that the 3-inch to 6-inch diameter round rock will allow influent to spread vertically and enter the rock drain matrix cross-section uniformly. As with the HSSF wetland, this simple inlet hydraulic control design allows for ease of construction with common materials, eliminates open water hazards, and minimizes heat loss by promoting subsurface flow conditions through the rock matrix. To facilitate maintenance, the perforated pipe will be fitted with a clean-out, allowing easy removal of biofilm that may develop within the pipe.

### 4.6.2 Matrix Material

The wetland pilot test confirmed that washed, rounded, granitic rock with a median diameter of two inches performed well at removing manganese and did not clog at 2 gpm, despite a build-up of iron precipitation within the rock drain. Literature on the subject of rock drain matrix material indicates that the use of limestone as an aerobic medium is preferable. In contrast to the pilot-scale rock drain, the rock type has been changed from round granitic rock to limestone in order to compare oxidation rates and determine if manganese removal can be enhanced. The wetland demonstration rock drain will utilize 1.5-inch to 2.0-inch nominal diameter, angular limestone. This rock size was selected to induce laminar flow conditions and promote the growth of manganese-oxidizing bacteria. The angularity and uniformity of the material size will allow for maximum interconnected porosity. Manganese dioxide is anticipated to be retained on the surface of the rock media.

### 4.6.3 Outlet Hydraulic Control Structure

The rock drain outlet hydraulic control structure is configured similarly to the inlet structure. A 6-inch diameter perforated pipe, bedded within 3-inch to 6-inch diameter washed, rounded rock, will capture flow across the width of the rock drain. The rock bedding will promote even distribution of flow toward the perforated pipe throughout the vertical cross-section of the rock drain. The perforated pipe will connect to an effluent pipe which will connect in series to an Agridrain. The operating water surface in the rock drain is expected to be below the surface of the rock matrix. Tailwater control from the Agridrain will allow for 2.0 feet of water level control.

From the Agridrain, an outlet pipe will drain to Pond 18. The spillway elevation of Pond 18 is 8826.50 ft amsl. To prevent water from backing up into the rock drain, a portion of the outlet pipe must be negatively sloped. This negatively sloped pipe was designed to be located near the rock drain in order to minimize the potential for freezing in the event that the HWTT is ever shut down during a cold weather period. Only the first ten feet of the 48-foot outlet pipe will be negatively sloped, the remaining pipe is sloped to drain into Pond 18.

### 4.6.4 Performance Monitoring

Three monitoring ports are proposed within the rock drain to monitor flow paths, water elevations, and hydraulic gradient through the system. The rock drain monitoring ports will be positioned along the central flow line of the rock drain and will be screened within the 1.5-inch to 2.0-inch nominal diameter angular limestone. These monitoring ports will be used to monitor inlet, midpoint, and outlet water elevations. Water elevation data will be used to calculate the hydraulic gradient through the rock drain. In addition, water quality parameters will be measured periodically to evaluate changes in water chemistry.

Rock drain influent, midpoint, and effluent water quality monitoring and sampling will be performed at the aeration channel outlet structure, midpoint monitoring port (located in the center of the rock drain), and rock drain effluent in the Agridrain to understand process chemistry. Semi-monthly analytical water sampling activities are anticipated for these three locations. Additional details regarding sampling and monitoring, including analyses and frequencies, will be presented under separate cover in a revised Performance Monitoring Plan.

## 5.0 VERTICAL WETLAND TREATMENT TRAIN

The VWTT unit processes were designed to evaluate the performance and applicability of constructing a vertical-flow wetland configuration at the site. The VWTT will consist of a settling basin (SB No. 2) connected in series to an anaerobic biotreatment cell and an aeration cascade. SB No. 2 and the biotreatment cell will be located in basins lined with 60 mil HDPE, while the aeration cascade will consist of a series of HDPE troughs. As with the HWTT, the influent will consist of a slipstream of water from the St. Louis Tunnel discharge channel, piped from the existing flow diversion point near the existing DR-3 surface water sampling location (Section 3.1). Effluent from the aeration cascade will flow into the eastern portion of Pond 18.

The VWTT has been design to remove iron, suspended solids, cadmium, manganese, and zinc via the following processes.

- *SB No. 2:* Gravitational settling of particulate and colloidal iron and TSS with and without flocculant addition and/or other pre-settling treatment applications, possibly including calcium silicate, flocculant logs, and/or an AFB.
- *Biotreatment cell:* Generation of aqueous sulfide via anaerobic SRB and subsequent removal of cadmium, iron, manganese, and zinc via sulfide precipitation.

The VWTT aeration cascade has been designed to remove sulfide and BOD via the following processes.

- Air stripping of $H_2S$ gas.
- Biological and abiotic oxidation of sulfide and BOD.

The following sections describe the design features and considerations for each of the VWTT unit processes.

### 5.1 HYDRAULIC PROFILE AND CONTROLS

The VWTT has been designed to operate at a target flow rate of 30 gpm. Flows ranging from 10 gpm to 50 gpm may be tested to mimic the natural variability present in the St. Louis Tunnel discharge and test the breakthrough point for each unit process.

The VWTT is designed such that the system is gravity fed and driven by the hydraulic head between the unit processes. Flow will be supplied to the VWTT by the flow diversion structure located downstream of the DR-3 surface water monitoring location (Section 3.1). Inline water level control structures (Agridrains) will be installed downgradient of both SB No. 2 and the biotreatment cell to allow variable water depths and HRTs to be set.

Total hydraulic head loss between the flow diversion structure and the VWTT effluent point at Pond 18 is 12.5 feet. The following elevations are planned for the VWTT.

**VWTT Design Elevations**

| Item | SB No. 2 | Biotreatment Cell | Aeration Cascade |
|---|---|---|---|
| Bottom elevation(s)<br>(ft amsl; inlet end / outlet end) | 8832.00 | 8832.50 | 8832.00 /<br>8826.00 |
| Depth (ft) | 6.0 | 6.0 | 2.0 |
| Substrate/wetted side slope (H:V) | 1:1 to 2.25:1 | 2:1 | 0:1 |
| Freeboard (ft) | 1.0 | 1.0 | 0.5 |
| Top of freeboard elevation<br>(ft amsl; inlet end / outlet end) | 8839.00 | 8838.50 | 8834.00 /<br>8828.00 |
| Freeboard side slope (H:V) | 2.25:1 | 2:1 | 0:1 |

## 5.2 SETTLING BASIN NUMBER 2

*Purpose:* Remove suspended solids and particulate and colloidal iron from wetland demonstration influent.

*Target Treatment Compounds:* TSS and total iron

*Effluent Treatment Goal:* <10 mg/L and <3 mg/L, respectively

Particulate and colloidal iron and TSS concentrations typically present at DR-3 (approximately 5 mg/L to 10 mg/L and 10 mg/L to 20 mg/L, respectively) will clog the organic substrate used in the biotreatment cell during long-term operation. Additionally, iron will interfere with sulfide precipitation of metals in the biotreatment cell by competing for available aqueous sulfide. SB No. 2 is designed to capture the majority of particulate Fe and TSS entering the system, prior to flow entering the biotreatment cell.

Use of an organic coagulant to assist removal of particulate iron and TSS will be tested using a flocculant injection system, as discussed in Section 4.2.2. SB No. 2 also has been designed to accommodate the use of calcium silicate as an additional treatment step upstream of SB No. 2 for iron and manganese removal. Design criteria for SB No. 2 are provided in the table below.

**Settling Basin No. 2 Design Criteria**

| | |
|---|---|
| Design flow rate, testing range (gpm) | 30, 10 to 50 |
| Width (ft) | 22.5 |
| Length (ft) | 91.5 |
| Surface area ($ft^2$) | 2,059 |
| Total depth (ft) | 7.0 |
| Depth of water (ft) | 6.0 |
| Average side slope (H:V) | 2.25:1, then 1:1 |
| Longitudinal bed gradient (%) | 0 |
| Volume (cubic feet [$ft^3$] / gallons [gal]) | 4,950 / 37,000 |
| HRT for 30 gpm at start-up (hours [hr]) | 20.5 |
| Assumed volume of sludge per year ($ft^3$ / gal) | 1,900 / 14,500 |
| HRT for 30 gpm after one year (hr) | 12.5 |

The following assumptions and considerations were incorporated into the SB No. 2 design.

- **Flow control/hydraulics** – SB No. 2 will be a gravity-fed, geomembrane-lined basin.

- **Size –** The 20.5-hour HRT was primarily selected to accommodate potential calcium silicate testing. Jar testing conducted by RMC indicated that up to 20 hours may be required to settle insoluble metal particulates created following the reaction of influent water with calcium silicate. The increased HRT compared to SB No. 1 in the HWTT (18 hours) also will allow for testing settling efficacy across a broader range of HRTs. The HRT at the maximum proposed flow rate of 50 gpm will be approximately 12 hours (40% reduction in HRT).

- **Shape –** SB No. 2 is designed with a long and narrow profile meant to prevent short-circuiting and maximize settling capacity. SB No. 2 also is designed with a central "sump" area three feet deep, three feet wide, and 77.5 feet long. The "sump" will serve to concentrate settled solids in the deepest part of the basin so they will be isolated from disturbance by wave action and be more easily removed during future maintenance activities.

- **Insulation** – HDPE insulating balls will be placed across the entire surface of SB No. 2 to minimize heat loss.

- **Sludge accumulation** – The sludge volume accumulation is estimated to be approximately 1,900 cubic feet over a one-year period, based on assumed solids removal of 9 mg/L, a sludge density of 8.34 pounds per gallon, and a solids concentration of 1.0%. It is anticipated that, over time, the sludge density will increase, thereby decreasing the sludge volume.

The following subsections describe key elements of SB No. 2 and the assumptions related to their design.

### 5.2.1 Inlet Hydraulic Control Structure

Inflow will occur through a PVC tee for flow dispersion.

### 5.2.2 Floating Baffle

A floating baffle will be installed across the width of SB No. 2. The floating baffle will enhance particle settling by reducing flow velocity and promoting an even distribution of water across the basin. The floating baffle will include a float across the water surface with a curtain hanging vertically below the float and extending to the sides and bottom of the basin. The curtain will span the entire width of the basin, perpendicular to the flow direction, near the inlet to maximize its effect.

### 5.2.3 Calcium Silicate

The use calcium silicate as a pre-treatment step for iron and manganese removal may be tested as part of the VWTT. Calcium silicate aggregate is highly refined stainless steel furnace slag that raises pH by consuming hydrogen ions in the following generalized reaction:

$$CaSiO_3 + 2H^+ + H_2O \rightarrow Ca^{2+} + H_4SiO_4 \text{ (monosilicic acid)}$$

If calcium silicate were employed, the St. Louis Tunnel discharge would be passed through reaction vessels filled with calcium silicate aggregate, which would raise the pH from circumneutral to approximately pH 9.5. Increasing pH to approximately pH 9.5 would precipitate significant quantities of manganese, iron, and other metals out of solution. Precipitated metals then would be retained within SB No. 2, and metal loading to the biotreatment cell would be reduced significantly. The biotreatment cell would provide removal of remaining cadmium, iron, manganese, and zinc and would reduce pH down to circumneutral levels for final discharge.

The decision whether to proceed with calcium silicate testing will be determined following a review of column testing results, which is expected to occur in February 2014. If calcium silicate treatment is incorporated into the VWTT, an addendum to this report will be submitted to the U.S. EPA describing the proposed design criteria.

### 5.2.4 Outlet Hydraulic Control Structure

The outlet flow control structure will consist of a perforated PVC collection pipe spanning the width of the downstream end of SB No. 2. The outlet collection pipe will be connected to an adjustable height outlet structure to allow for varying HRTs. Perforated pipe diameters and hole sizes were designed oversized (0.75 inch) to prevent potential clogging or biofouling.

## 5.3 ANAEROBIC VERTICAL FLOW BIOTREATMENT CELL

*Purpose:* Promote the growth of SRB in an anaerobic environment and induce biological sulfate reduction for treatment of dissolved cadmium, iron, manganese, and zinc, present in the St. Louis Tunnel discharge, to form insoluble metal sulfides.

*Target Treatment Compounds:* Cadmium, iron, manganese, and zinc

*Effluent Treatment Goal:* <0.5 µg/L, <1,000 µg/L, <1,500 µg/L, and <100 µg/L, respectively

The biotreatment cell will be a downflow, gravity-fed, geomembrane-lined basin designed to generate sulfide by anaerobic SRB and remove cadmium, iron, manganese, and zinc by metal sulfide precipitation. SRB are obligate anaerobes that metabolize sulfate and organic carbon to produce aqueous sulfide species and bicarbonate. Concentrations of other metals that are present at relatively low concentrations (e.g., copper, lead, nickel, and others) also will be reduced by the same mechanism.

Organic carbon will be supplied to the SRB via an organic substrate consisting of a mixture of wood chips, wood shavings, hay, and manure. Experience at similar sites has shown that the available organic carbon in the substrate mix is sufficient for seven to ten years of effective operation. Additionally, mechanical agitation of the substrate can be used to extend the usable life of the substrate by up to 25%.

Elemental sulfur will not be incorporated into the VWTT organic substrate. Sulfate is naturally present in the St. Louis Tunnel discharge in relatively high concentrations (typically >600 mg/L), and stoichiometric calculations indicate that sulfate concentrations exceed the minimum concentration required to precipitate 100% of the metals in St. Louis Tunnel discharge by nearly two orders of magnitude. Use of elemental sulfur (i.e., sulfur prills) has been shown to increase sulfide production at low water temperatures. However, heat loss calculations indicate that the use of HDPE insulating balls in SB No. 2 and the biotreatment cell should maintain sufficient water temperature for adequate sulfide generation from sulfate reduction alone. Use of elemental sulfur in the HWTT HSSF wetland matrix and not the VWTT biotreatment cell organic substrate will help determine whether elemental sulfur would be required in a full-scale system.

The key design considerations for the biotreatment cell included HRT, matrix media size and composition (which relate to porosity and hydraulic conductivity), lateral water distribution, and inlet and outlet structure clogging mitigation. Biotreatment cell design criteria are provided below.

**Biotreatment Cell**

| | |
|---|---|
| Design flow rate, testing range (gpm) | 30, 10 to 50 |
| Top width (ft) | 44 |
| Top length (ft) | 68 |
| Basin surface area ($ft^2$) | 2,992 |
| Total depth (ft) | 6.0 |
| Depth of freeboard (ft) | 1.0 |
| Depth of organic substrate (ft) | 4.0 |
| Depth of drainage rock (ft) | 1.0 |
| Side slope (H:V) | 2:1 |
| Longitudinal bed gradient (%) | 0 |
| Volume of organic substrate ($ft^3$ / gal) | 9,600 / 72,000 |
| Particle diameter (inch) | 0.5 to 2.0 |
| Porosity of organic substrate (%) | 30 |
| Pore volume (gal) | 21,600 |
| Hydraulic conductivity (ft/d) | 280 |
| HRT at design flow (hr) | 12 |

The following assumptions and considerations were incorporated into the biotreatment cell.

- The biotreatment cell size was determined by scaling up a 24-hour, 30 gpm, empty-bed HRT by 66% to accommodate winter water temperatures following heat loss in SB No. 2. Results of column testing, conducted in November and December 2013 by RMC using St. Louis Tunnel discharge, indicate that the 12-hour HRT is appropriate for production of adequate but not excessive concentrations of sulfide.

- The total depth of the VWTT's anaerobic biotreatment cell is six feet (including freeboard), which is only 0.2 foot deeper than the HSSF wetland. Because there is no significant difference in total depth, a full-scale vertical-flow system has no greater potential for complications resulting from the potential presence of shallow groundwater conditions.

- The surface area for the VWTT biotreatment cell is nearly 50% smaller than the HWTT HSSF wetland, which could reduce land area requirements for a full-scale system significantly.

- Vertical-flow systems are potentially less likely to develop short-circuiting and preferential flow paths than horizontal-flow systems. Flow in a vertical-flow system is more broadly diffused and travels a much shorter total distance between the influent and effluent points. The potential for development of short-circuiting and preferential flow paths is directly proportional to the distance flow must travel through the substrate/matrix material.

- Vertical-flow systems are potentially less likely to develop hydraulic conductivity problems than horizontal-flow systems. Vertical-flow systems inherently “stack” water between the influent distribution and effluent collection points, which creates hydraulic head. That hydraulic head can be utilized to push water through the substrate/matrix material more effectively.

- Compared to the biotreatment cell’s expected removal efficiencies for cadmium and zinc (>90% for both), the expected removal efficiency for manganese is low (approximately 25%). The anticipated manganese removal efficiency is based on experience at similar sites and the results of recent column testing. Lower removal efficiency is attributed to manganese’s relatively high solubility under anaerobic conditions and relatively low affinity for sulfide (compared to cadmium, iron, and zinc). Minimal manganese removal may be required to meet future site discharge limits. However, if more stringent manganese discharge limits are implemented, manganese removal with aerobic manganese-oxidizing bacteria has been successfully tested by AMEC (AMEC, 2013b) and will be further tested as part of the HWTT (Section 4.6). Such a manganese removal process could be incorporated into the VWTT without issue. Additionally, the use of calcium silicate for manganese removal may be implemented as part of the pre-treatment for the VWTT (Section 5.2.3).

### 5.3.1 Inlet Hydraulic Control Structure

Inflow to the biotreatment cell will be distributed across the surface through a network of perforated 3-inch diameter PVC pipe laterals spaced at five-foot intervals across the entire cell surface. Influent PVC pipe laterals will be bedded into the upper six inches of the organic substrate. Perforated pipe diameters and hole sizes were designed oversized to prevent potential clogging or biofouling.

It is anticipated that some surface ice formation may occur during winter operations. This condition has been observed at similar sites and has not been a significant operational concern. The influent piping network bedded into the upper six inches of the organic substrate is anticipated to be below the likely depth of ice formation. Heat loss calculations using mean water temperatures at DR-3 indicate that influent water temperatures should remain above 50°F with the use of HDPE insulating balls in SB No. 2 (Section 5.2). In addition, HDPE insulating balls placed on the biotreatment cell surface will minimize heat loss, maximize biological activity, and decrease the potential for ice formation.

The proposed influent and effluent pipe networks are designed to minimize short-circuiting potential by evenly distributing influent across the substrate surface and promoting uniform flow through the substrate. Some settlement of the substrate is expected to occur after installation. Flexible couplers will be installed on influent pipe junctions to allow the piping to accommodate any differential settling that occurs.

### 5.3.2 Matrix Material

This substrate composition was selected based on previous treatment experience at similar sites. Column testing results indicated that the selected substrate mix is appropriate and effective. Minimal floating of the substrate mix is anticipated based on experience at similar sites. Substrate hydraulic conductivity will be maintained by effective solids pre-treatment and removal (SB No. 2) and appropriate substrate selection. Wood species specified are available in the region and have been used successfully at similar sites. RMC's experience at similar sites has shown that use of aged wood products is typically a more important consideration than specific wood species.

Approximately seven gallons of substrate used during column testing, conducted in November and December 2013 by RMC using St. Louis Tunnel discharge, will be incorporated into the substrate as a source of bacterial inoculum. The organic substrate composition will consist of the materials presented in the following table.

**Biotreatment Cell Organic Substrate Composition (Percentage by Volume)**

| | |
|---|---|
| Wood chips, 1.0-inch to 2.0-inch diameter pine, fir, spruce, and/or aspen (as available), produced from wood aged for a minimum of one year | 65 |
| Wood shavings, 0.5-inch to 1.0-inch diameter pine, fir, spruce, and/or aspen (as available), produced from wood aged for a minimum of one year | 25 |
| Manure, steer, composted | 5 |
| Hay, alfalfa, chopped | 5 |
| Inoculum (gallons) | 7 |

The substrate mix was selected with the following considerations.

- Wood chips: Large wood chips provide a long-term source of organic carbon for SRB. Large wood chips also provide large pore spaces within the substrate and promote maintenance of hydraulic conductivity.

- Wood shavings: Wood shavings have substantially higher surface area than wood chips and provide a more readily available source of organic carbon during system start-up and early operation. Additionally, some relatively finely-textured material (compared to wood chips) is required for effective filtration and retention of metal sulfide precipitates. The selected quantity of wood shavings is high enough to provide filtration/retention without overly reducing hydraulic conductivity.

- Hay: Hay provides an additional source of more readily available organic carbon during system start-up and early operation. Hay's differing physical structure from the wood products described above (fibers) also aids filtration and retention of metal sulfide precipitates and maintenance of hydraulic conductivity. Alfalfa hay also has a low carbon to nitrogen ratio, which may aid microbial growth.

- Manure: Steer manure provides very readily available organic carbon during system start-up and early operation. Manure also provides a source of bacterial inoculum, as SRB are naturally present in the digestive tracts of cattle and other ruminant animals. Manure mainly consists of fine particles, but since it comprises a very small percentage of the substrate, the fines are not expected to significantly impact hydraulic conductivity.

- Inoculum: SRB are common in nature and will thrive without purposeful inoculation if provided appropriate conditions (i.e., anoxic water, organic carbon, and sulfate). However, previous treatment experience at similar sites indicates that colonization occurs more rapidly if inoculum sources are provided. Since the VWTT is planned to operate for one year, rapid colonization is desirable. Therefore, the substrate used in column testing will be incorporated into the substrate to provide an additional inoculum source.

The drainage layer constituting the bottom one foot of the biotreatment cell will consist of 1.5-inch nominal diameter washed angular limestone rock. This material is identical to the rock that will be used in the HWTT aerobic rock drain (Section 4.6).

### 5.3.3 Outlet Hydraulic Control Structure

Effluent from the anaerobic biotreatment cell will be collected through a network of perforated 3-inch diameter PVC pipe laterals spaced at five-foot intervals across the entire cell bottom. Perforated pipe diameters and hole sizes were designed oversized to prevent potential clogging or biofouling. Effluent laterals will be bedded into a one-foot layer of limestone drainage rock.

The effluent pipe will be connected to an adjustable height outlet structure that will allow for up to two feet of water level adjustment and allow for variable HRTs to maintain effluent sulfide concentrations in the target range of 1 mg/L to 5 mg/L. Each foot of water level adjustment will reduce HRT by approximately 50%. Water level adjustment will be facilitated by weir slats that can be added or removed to adjust the outlet elevation. The weir slats are available in 2-inch, 5-inch, or 7-inch increments. It is expected that the water level in the biotreatment cell will be set to the maximum elevation during start-up and winter operations to accommodate the reduced bacterial activity expected during these periods. The water level will be reduced as-needed during warm-weather periods, when increased bacterial activity is expected.

### 5.4 AERATION CASCADE

*Purpose:* Air-strip $H_2S$ gas, consume sulfide and BOD, and re-oxygenate the biotreatment cell effluent prior to discharging to Pond 18.

*Target Treatment Compounds:* Sulfide, BOD, and DO

*Effluent Treatment Goal:* <1 mg/L, <30 mg/L, and >5 mg/L, respectively

Biological oxidation of sulfide proceeds up to five orders of magnitude more rapidly than abiotic oxidation of sulfide, with the highest rates of biological sulfide oxidation achieved by aerobic chemotrophic microbes (Luther et al., 2011). Luther et al. (2011) also demonstrated that the presence of low concentrations of Fe(II) and Mn(II) (as low as approximately 10 µg/L and 100 µg/L, respectively) increases abiotic rates of sulfide oxidation by up to three orders of magnitude. Because dissolved Fe(II) and Mn(II) are both expected to be present in aeration cascade influent, the aeration cascade will employ both biological sulfide oxidation and abiotic sulfide removal processes (abiotic sulfide oxidation catalyzed by dissolved Fe(II) and Mn(II) and air stripping of $H_2S$ gas).

RMC's extensive experience with passive sulfide and BOD removal following anaerobic biotreatment indicates that one or both of the following treatment types is required.

- Long HRT (12 to 24 or more hours) in an established shallow aerobic wetland.
- Vigorous aeration in a pool-and-drop cascade or channel.

Establishment of a shallow aerobic wetland is not feasible since the wetland demonstration test period will have concluded prior to the growth of sufficient vegetation. Thus, use of an aeration cascade was selected for the wetland demonstration. Use of a long-HRT established shallow aerobic wetland may be feasible in a full-scale system. If needed, a long-HRT established shallow aerobic wetland could be used in combination with, or in place of, an aeration cascade in a full-scale system. Such a wetland could potentially be located in the current footprint of Ponds 5 through 10.

The aeration cascade will consist of a series of five HDPE troughs, each two feet deep, two feet wide, and ten feet long. Water will free-fall 1.5 feet between each trough into open water to maximize air entrainment and subsequent air-stripping of $H_2S$ gas and restoration of DO. The downgradient half of each trough will be partitioned and filled with angular limestone rock to provide surface area for the growth of aerobic sulfide-oxidizing bacteria. Aeration cascade design criteria are provided below.

**Aeration Cascade Design Criteria**

| | |
|---|---|
| Design flow rate, testing range (gpm) | 30, 10 to 50 |
| Anticipated DO concentration at inlet (mg/L) | 0 |
| Target DO concentration at outlet (mg/L) | >5 |
| Total length (ft) | 50 |
| Trough length (ft) | 10 |
| Trough width (ft) | 2 |
| Trough depth (ft) | 2 |
| Rock depth (ft) | 1.5 |
| Total fall height (ft) | 7.5 |
| Fall height between troughs (ft) | 1.5 |
| Limestone rock nominal diameter (inch) | 3 |
| HRT at target flow rate (min) | 28 |

### 5.4.1 Flow Control and Hydraulics

Flow through the aeration cascade will be entirely gravity-driven. Water depth will be controlled by the spillway elevation of each trough; variable depths are not required. The number of troughs was selected based on the available drop to the Pond 18 outlet elevation; total hydraulic head loss through the aeration cascade will be approximately 7.5 feet. This total fall height is within standard criteria for cascade aerators, which typically range from 6.5 feet to 23 feet (TU Delft, 2010). Sampling may be conducted at one or more of the intermediate troughs within the cascade to determine if one or more of the troughs could be eliminated from a full-scale design; sampling at the aeration cascade effluent will determine if additional troughs are required.[5]

Trough depth and the 1.5-foot fall height between troughs was selected based on established design criteria for cascade aerators (TU Delft, 2010) to maximize aeration efficiency. Minimum trough depth is typically two-thirds of the fall height, which prevents the falling water jet from reaching the bottom (TU Delft, 2010). Thus, air bubbles are dragged to a maximum depth,

[5] Additional details regarding sampling and monitoring, including analyses, locations, and frequencies, will be presented under separate cover in a revised Performance Monitoring Plan.

which results in a maximum gas transfer time. The trough depth was increased to equal the fall height to provide increased HRT for biological sulfide oxidation.

Scale-up of the aeration cascade design for a full-scale system would be limited to increasing the width of the cascade proportional to flow. Thus, a 1,000-gpm system would require an aeration cascade 67 feet wide and 50 feet long, a minimal footprint compared to the other required unit processes. Total drop would not need to increase. Given that there is approximately 60 feet of elevation change between DR-3 and DR-6 and approximately 40 feet of elevation change between DR-3 and the southern boundary of Pond 11, the aeration cascade's total drop of 7.5 feet appears fully compatible with a potential full-scale system.

#### 5.4.2 Matrix Material

The downgradient half of each aeration cascade trough will be filled with 3-inch nominal diameter angular limestone rock to provide surface area for the growth of aerobic sulfide-oxidizing bacteria. The rock also will provide precipitation sites for elemental sulfur that oxidizes and precipitates from solution. The rock size was selected to be small enough to provide a large surface area for the growth of aerobic sulfide-oxidizing bacteria but also large enough to provide large void spaces that will promote flow and minimize the potential for clogging or biofouling.

A partition will contain the rock. The lower half of the partition will be perforated to maximize flow through the rock and associated sulfide-oxidizing bacteria. The rock will not be inoculated; sulfide-oxidizing bacteria are common in the environment and are expected to naturally colonize the media.

Heat loss calculations indicate that operationally significant ice accumulation in the aeration cascade is unlikely at typical winter temperatures.

## 6.0 HEALTH, SAFETY, SECURITY, AND ENVIRONMENT

Specific HSSE considerations that will be mitigated through wetland demonstration design are summarized below. Additional hazards associated with each treatment train will be mitigated by procedures identified through Control of Work risk assessments and Hazard Identification and Process Safety checks.

### 6.1 WORKING NEAR WATER

All activities conducted near open water will be performed in accordance with the *BP Guidance on Practice for Design and Construction Activities Adjacent to or In Water Bodies*. The two settling basins and VWTT biotreatment cell will be fitted with monitoring equipment such that field personnel may remain greater than six feet from the water's edge. Chain link fencing will be erected around the perimeters of the settling basins and VWTT biotreatment cell to provide physical barriers. Access will be through locked gates, and signs will be displayed on the fencing indicating that the area contained by the fence presents clear and present hazards to trespassers.

The settling basins will be equipped with ropes and provided with brightly colored floats to give persons who might fall into a basin a means to reach the water's edge. For those basins with a drowning hazard, the side slopes have been reduced to 2.25:1 to reduce the potential of entrapment.

Throw rings will be provided any time work is required to be performed within six feet of the water's edge. The interval between throw ring locations will not exceed 200 feet, and/or throw rings will be located within 100 feet of the work. Personal floatation devices (PFDs; type I, II, III, or V vests) with whistles will be inspected prior to each use and will be required wherever there may be a drowning hazard. Alternatively, a restraining device may be employed. During potentially hypothermic conditions, PFDs will be insulated, and rescue hooks with poles will be stationed in the work area for personnel extraction.

## 6.2 OVERFLOWS

Several conditions could result in overflowing water at the wetland demonstration unit processes or the St. Louis Tunnel discharge channel. Such conditions include excessive storm water and blocking or clogging of outlets and inlets. To minimize the potential for unit processes to overflow, each unit process is designed to maintain a minimum of one foot of freeboard above the maximum anticipated operational water level. Additionally, Agridrain hydraulic control structures with adjustable PVC weir slats will allow operators to adjust water levels and compensate for potential clogging or blocking of unit processes.

To minimize storm water flow into the system, the area surrounding the HWTT and VWTT will be graded away from the unit processes. Grading will direct any unlikely wetland demonstration overflows and/or excessive storm water to Pond 18. Overflows and excessive storm water are anticipated to be infrequent, and the erosion potential of such events is not anticipated to cause damage that cannot be repaired quickly. Therefore, the north bank of Pond 18 will not be armored. Outfalls to Pond 18 for both the HWTT and VWTT will be protected by rock rundowns. Low-rise diversion berms will be constructed along the western edge of the wetland demonstration to prevent water from entering the Dolores River in the event of an overflow.

### 6.3 HYDROGEN SULFIDE GAS

The inlet hydraulic control structures for the aeration features in each treatment train also will function as the variable depth outlets for the anaerobic unit processes (HWTT HSSF wetland and VWTT biotreatment cell). As such, these inlet hydraulic control structures have the potential to release $H_2S$ gas; the quantity and concentration of the releases is unknown.

The HWTT aeration channel has been designed to encourage the precipitation of elemental sulfur, thereby reducing the release of $H_2S$ gas. The aeration channel inlet is designed so that the sulfide-bearing solution (i.e., HSSF wetland effluent) enters the bottom of the inlet Agridrain in anoxic conditions and flows upwards through synthetic trickle media as the partial pressure of oxygen increases. The media will provide surface area for biological sulfide oxidizers to convert the incoming sulfide to sulfur.

The VWTT biotreatment cell will be operated to maintain effluent residual sulfide within a target range. Sulfide production will be managed so that sufficient metals removal is achieved, without the use of sulfur prills in the organic substrate, while excess $H_2S$ gas generation is minimized. BOD and residual aqueous sulfide in the final discharge also will be minimized. Additionally, at other constructed wetland treatment sites, the vertical down-flow flow path has been observed to limit the ability of $H_2S$ gas to migrate upward through the organic substrate.

Both anaerobic unit processes will include a weir and drop for water from the inlet structure to the water level of the aeration channel/cascade to allow for the off-gassing of residual $H_2S$ gas in a controlled location and in a well-ventilated area. $H_2S$ sensors will be used to monitor $H_2S$ gas concentrations near the $H_2S$ gas sources and in the adjacent breathing zones. Additional sensors may be added as necessary, pending the results of initial $H_2S$ gas monitoring. The $H_2S$ gas sensors will be portable and incorporated into the telemetry system (Attachment A) so that they may be monitored remotely. Double wire T-post fencing will be erected around the perimeters of the HWTT aeration channel and VWTT aeration cascade to establish $H_2S$ exclusion zones.

### 6.4 CONSTRUCTION MATERIALS

The structures used for hydraulic controls as well as housing for valves and flow meters were evaluated to identify alternate materials that are lighter and easier to install than precast concrete. Materials that have been identified include an Agridrain PVC custom inlet box to replace the SB No. 1 inlet and HDPE vault boxes to replace the precast concrete boxes previously selected.

## 6.5 COAGULANT

The ClearTech CTI 4900 coagulant selected for use in SB No. 1 was evaluated for HSSE considerations. CTI 4900 poses minimal health and safety risks; aluminum chlorohydrate is used as a coagulant for drinking water and is approved by the FDA for human contact in anti-perspirants. Human exposure may result in mild irritation. Therefore, no adverse HSSE concerns are anticipated while using this coagulant. Coagulant dosing rates will be optimized based on the results of laboratory bench-scale testing (Section 4.2.2) and initial wetland demonstration implementation. Any residual coagulant that may pass through the settling basins is anticipated to sorb to the SF wetland, HSSF wetland, and biotreatment cell matrices. Therefore, environmental release of CTI 4900 is anticipated to have negligible consequences.

The freezing point for CTI 4900 is -7°C (19°F). To reduce the potential for coagulant freezing, the chemical feed system will be placed within the heated and insulated former Lime Treatment Plant building. To mitigate a potential splash hazard from the injection pump, the pump will be housed within a locked Chemical Feed Pump Containment Shelf (shelf). The shelf will be mounted to the wall and will have a built-in viewing window to allow operators to visually check for leaks. The shelf will serve as spill control; liquids captured in the enclosure will flow to a 0.25-inch discharge tube that will convey captured chemical back to the tote or the secondary containment. In addition to the pump shelf, the chemical feed pump is constructed with a leak sensor located within the pump head, such that a release of chemical in the pump results in the pump stopping automatically.

A Haws Model 7601.37 (or similar) portable, pressurized eyewash with body spray will be kept inside the Chemical Feed Station at all times, as a precaution when working around the chemical feed system. The eyewash is a 37-gallon, air pressure operated system equipped with a body spray attachment. A plug-in air compressor will accompany the eyewash in order to maintain full pressure charge in the eyewash tank. Although the Chemical Feed Station will be located within a heated building, a thermal blanket also will be placed around the eyewash to maintain tepid water temperature suitable for eye contact.

Administrative controls will involve personal protective equipment (PPE) requirements for coagulant injection system operators and technicians. Personnel visually inspecting the chemical feed system will be required to wear site-specific Level D PPE while within the Chemical Feed Station. The shelf containing the chemical feed pump will be locked to restrict access to the pump. During scheduled inspections of the pump and associated tubing, pump maintenance, and tote transfers, personnel shall be required to wear a full-face shield and de-energize and depressurize the system prior to unlocking and lifting the lid to the pump shelf.

## 7.0 REFERENCES


AECI, 2011 to 2013, Rico Surface Water Sampling, Supplemental Surface Water Quality Monitoring, Rico, Colorado, Data Summary Reports, prepared for Atlantic Richfield Company, multiple reports.

AMEC, 2013a, Rico-Argentine Mine Site Constructed Wetland Treatability Demonstration Technical Specifications Issued for Construction, prepared for Atlantic Richfield Company, June 28.

---, 2013b, St. Louis Tunnel Discharge Constructed Wetland Pilot Scale Test Completion Report Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01, Dolores County, Colorado, prepared for Atlantic Richfield Company, November.

Arnosti, C. and Jorgensen, B.B., 2003, High activity and low temperature optima of extracellular enzymes in Arctic sediments: Implications for carbon cycling by heterotrophic microbial communities, Marine Ecology - Progress Series, Vol. 249, p. 15-24

Atlantic Richfield, 2013, St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study Work Plan Revision 1, Rico-Argentine Mine Site – Rico Tunnels, Operable Unit OU01, Dolores County, Colorado, prepared by AMEC Environment & Infrastructure, October.

Hedin, R.S., 2008, Iron removal by a passive system treating alkaline coal mine drainage, Min Water Environ, 27:200-209 DOI 10.1007/s10230-008-0041-9.

Knoblauch, C. and Jorgensen, B.B., 1999, Effect of temperature on sulphate reduction, growth rate and growth yield in five psychrophilic sulphate-reducing bacteria from Arctic sediments, Environmental Microbiology, Vol. 1, No. 5, 01.10, p. 457-467.

Kristensen, E., Saiyed, I.A., and Allan, H.D., 1995, Limnol Aerobic and anaerobic decomposition of organic matter in marine sediment: Which is fastest? Oceanogr. 40(8), p. 1430-1437.

Luther, G.W. III, Findlay, A.J., MacDonald, D.J., Owings, S.M., Hanson, T.E., Beinart, R.A., and Girguis, P.R., 2011, Thermodynamics and Kinetics of Sulfide Oxidation by Oxygen: A Look at Inorganically Controlled Reactions and Biologically Mediated Processes in the Environment, Frontiers in Microbiology, published online 9 April, Microbiol. 2:62. doi: www.10.3389/fmicb.2011.00062

MWH, 2013, MWH Bench-Scale Treatability Test Results for the Rico Mine St. Louis Adit Discharge, technical memorandum prepared for AMEC, October 21.

NRCS, 2013, SNOTEL Site Scotch Creek Colorado, National Resources Conservation Service, National Water and Climate Center, United States Department of Agriculture, available at http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=739&state=co.

Paser, 1996. Characterization of and treatment recommendations for the St. Louis Adit Drainage and associated settling ponds in Rico, Colorado. Thesis, Colorado School of Mines. August.

TU Delft, 2010, Aeration and Gas Stripping, TU Delft OpenCourseWare, January 2010.

U.S. EPA, 1995. Solid Waste Disposal Facility Criteria – Technical Manual, Ch. 4, Subpart D, Design Criteria.

Watson, C.C., Walters, R.W., and Hogan, S.A., 1998, Aeration Performance of Low Drop Weirs, J. Hydraul. Eng. 1998.124:65-71.

Younger, P.L., Banwart, S.A., and Hedin, R.S., 2002, Passive Treatment of Polluted Mine Waters, B.J. Alloway and J.T. Trevors Ed. Mine Water Hydrology, Pollution, Remediation. Chapter 5, pgs. 311-393. Kluwer Academic Publishers, London.

TABLE

**TABLE 1**
**ST. LOUIS TUNNEL DISCHARGE FLOW RATES**
Rico-Argentine Mine Site
Dolores County, Colorado

| Month | Monthly Average Flow Rate[1] (gpm) |
|---|---|
| May 2011 [2] | 644 |
| June 2011 | 775 |
| July 2011 | 869 |
| August 2011 | 870 |
| September 2011 | 859 |
| October 2011 | 801 |
| November 2011 | 718 |
| December 2011 | 691 |
| January 2012 | 745 |
| February 2012 [2] | 587 |
| March 2012 [2] | 617 |
| April 2012 | 593 |
| May 2012 | 618 |
| June 2012 | 665 |
| July 2012 | 694 |
| August 2012 | 686 |
| September 2012 | 661 |
| October 2012 | 620 |
| November 2012 | 568 |
| December 2012 [2] | 537 |
| January 2013 [3] | -- |
| February 2013 [2] | 491 |
| March 2013 [4] | 491 |
| April 2013 [4] | 491 |
| May 2013 [4] | 551 |
| June 2013 [2,4] | 551 |
| July 2013 [2,4] | 550 |
| August 2013 [4] | 550 |
| September 2013 [4] | 550 |
| October 2013 [2,4] | 550 |

**Notes:**
1. Average monthly flow rates were determined by averaging the available ultrasonic sensor flow measurements recorded at monitoring location DR-3 during any given month. Flow data was provided by Anderson Engineering Company, Incorporated.
2. Flow data was only available for part of this month.
3. No flow data was recorded during January 2013.
4. Due to a possible sensor error, only minor flow rate fluctuations were observed after March 2013.

## ATTACHMENT A

Monitoring Instrumentation and Telemetry

# Technical Memorandum

To: Anthony R. Brown, Environmental Manager
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CC: Terry Moore, Atlantic Richfield
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From: Bryan Wheeler, AEEC

Date: January 31, 2014

Subject: Monitoring Instrumentation and Telemetry
St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study, Rico-Argentine Mine Site, Dolores County, Colorado

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## Contents

# 1 Introduction

There are safety and logistical challenges associated with obtaining environmental data at the Rico-Argentine Mine Site (site) in Dolores County, Colorado. These challenges include inaccessibility due to extreme weather conditions (primarily snow and rain), seasonally unsafe site conditions (i.e., avalanche zones), and remoteness. This technical memorandum describes instrumentation and controls recommended for the St. Louis Tunnel Discharge Constructed Wetland Demonstration Treatability Study (wetland demonstration) involving the Horizontal Wetland Treatment Train (HWTT) and the Vertical Wetland Treatment Train (VWTT). These recommendations include process monitoring instrumentation and programmable logic controller (PLC) network with a PC server that has remote data access. Low voltage power requirements are documented at the end of this technical memorandum.

# 2 Instrumentation and Telemetry

The telemetry system will consist of seven basic elements:

1. Instrumentation including flow meters, multi-parameter water quality meters, and hydrogen sulfide ($H_2S$) gas detectors.
2. A data logger translates the sonde serial data into Modbus for one of the controllers.
3. A radio receiver takes $H_2S$ detector data and sends it to the second controller.
4. SCADApack controllers; one controller, SP-1, accepts the flow meter analog and pulse output and the multi-parameter sonde information, while the second controller, SP-2, accepts $H_2S$ detector data from the radio receiver.
5. A router for combining data from multiple controllers.
6. A host PC computer server that receives and manages the data from the controllers.
7. Third party software installed on the PC server providing an interface that shares data to and from the controllers.

These components will be incorporated into both the HWTT and the VWTT, encompassing the entire wetland demonstration.

The purpose of the telemetry system is to demonstrate function, performance, and maintenance requirements of the system in preparation for a full-scale design and to reduce operational requirements during the wetland demonstration.

Instrumentation was selected for use in the wetland demonstration in order to identify and evaluate various sensors and approaches to telemetry that can be used as part of a long-term remedy for the site. All instrumentation, excluding the flow meters, will be reusable for a full-scale system. Instrumentation requirements for system performance, operations, and maintenance monitoring will be described in a Performance Monitoring Plan, which will be issued under separate cover.

The design drawings listed below provide references to diagrams, locations, equipment tag numbers, quantities, and installation details. Of particular interest are diagrammatic sheets I-1, Piping and Instrumentation Diagram, and E-2, Telemetry / Network.

E-SERIES PLANS: ELECTRICAL AND TELEMETRY

| |
|---|
| CCS-1 CIRCUIT SCHEDULE |
| CCS-2 CONDUIT SCHEDULE |
| E1 ONE-LINE DIAGRAM & PANELBOARD SCHEDULE |
| E2 TELEMETRY/NETWORK |
| E3 OVERALL CONDUIT |
| E4 CONDUIT BLOCK DIAGRAM |
| E5 CIRCUIT PLAN |
| E6 TRENCH DETAIL |
| E7 BOX DESIGN CJB-2 & CJB-3 |
| E8 BOX DESIGN CJB-1 |
| E9 BOX DESIGN PLC PANEL |
| E10 BOX DESIGN CJB-2 & CJB-3 |
| E11 GROUNDING DETAILS |
| I1 PIPING AND INSTRUMENTATION DIAGRAM |

ADDITIONAL DRAWINGS RELATED TO INSTRUMENTATION INSTALLATION

| |
|---|
| G4 MONITORING LOCATION PLAN |
| H14 HSSF WETLAND DETAILS (temperature profile and monitoring port) |
| H18 ROCK DRAIN DETAILS (temperature profile and monitoring port) |
| H21 SECTIONS AND DETAILS SHEET (details 1 and A, location of WQ instruments) |

| |
|---|
| H25 MONITORING EQUIPMENT INSTALLATION DETAILS |
| V7 SECTIONS AND DETAILS SHEET (detail 2, location of WQ-09) |
| V13 SECTIONS AND DETAILS SHEET (detail 2, location of WQ-09) |

## 2.1 Selected Instrumentation

Instrumentation that will be incorporated into the telemetry system includes Toshiba GF63X/LF62X flow meters, Detcon CXT $H_2S$ gas detectors, and YSI Inc. EXO2 multi-parameter sondes (sondes). The sondes are capable of measuring pressure, temperature, conductivity, pH, oxidation reduction potential (ORP), and dissolved oxygen.

The influent flow rates for each treatment train will be monitored after the flow diversion box. Flows also will be monitored downstream of the effluents of both the HWTT and VWTT.

Sondes will be used to monitor water quality and pressure at multiple locations in both the HWTT and VWTT. This information will document performance of the treatment trains. The installation of sondes is detailed in a table that appears in sheet I-1, Piping and Instrumentation Diagram. Note that sondes at locations WQ-01, WQ-03, and WQ-05 are not connected to the telemetry system, as they are existing units. While the design drawing information takes precedence with its revisions, a water quality instrument table is presented below for convenience.

Hydrogen sulfide gas concentrations will be monitored using $H_2S$ detectors. Of greatest interest are the maximum concentrations released from the HWTT aeration channel, VWTT aeration cascade, and around the perimeter of these unit processes.

Three $H_2S$ detectors are proposed near the HWTT aeration channel. This includes one near the aeration channel inlet (H2S01), where the highest gas concentration is anticipated, and two near the existing access road (H2S02 and H2S03). Two sensors are proposed near the VWTT aeration cascade, one near the inlet (H2S05), again where the highest gas concentration is anticipated, and another near the existing access road (H2S04). Measuring the highest $H_2S$ gas produced is needed to evaluate practices for operator safety. Detectors near the access roads will help monitor possible impacts to the public since the access road is Forest Service property and open to the public.

Table 1 – Water Quality Instrument List

| Demonstration Study Unit Operation | Location Code | Water Quality Monitoring Instrument | Sonde equipped with Dissolved Oxygen / Conductivity / pH / ORP / Temperature | Sonde also equipped with Pressure | Sonde also equipped with Turbidity |
|---|---|---|---|---|---|
| HWTT Settling Basin SB NO. 1 Effluent | SB1EFF | WQ-2 | X | X | X |
| HWTT HSSF Wetland Basin | HSSFW | WQ-4 | X | X | |
| HWTT Rock Drain Effluent | RDEFF | WQ-6 | X | X | |
| VWTT Settling Basin SB NO. 2 Effluent | SB2EFF | WQ-7 | X | X | X |
| VWTT Biotreatment Cell Effluent | BTEFF | WQ-8 | X | X | |
| VWTT Aeration Cascade Effluent | AC2EFF | WQ-9 | X | | |

## 2.2 Key Design Elements/Assumptions

Electromagnetic flow meters will be installed at the influent and effluent of the HWTT and VWTT. The flow meters are comprised of a flow element and a transmitter. The transmitters are mounted on the piping element. The influent flow meter will provide local indication of flow rate, while the effluent meter must be read from the Former Lime Treatment Plant Building. The influent meter has local indication to assist with the manual adjustment of the influent flow control valve. The flow meters will be powered by 120 volt AC power supplied from the Former Lime Treatment Plant Building.

The selected flow meters require little maintenance and infrequent calibration and cleaning. The manufacturer recommends the use of a verification tool approximately once a year to prove functionality and response of the flow meter. More frequent cleaning may be required where extreme fouling is present.

Sondes were selected for water quality and water level monitoring. Sondes were selected because equivalent technology (YSI 6920 Sonde) has been used successfully at the site. The sondes have internal batteries and also will be powered by an external 12 volt DC power source.

The sondes do not include local indication for any of the water quality parameters. A handheld device from the sonde manufacturer will be available to provide local indication of instrument output to assist in performing calibrations.

The sondes are resistant to fouling and maintain calibration for extended periods of time. Multiple sensors can be calibrated concurrently while installed in a single sonde device. Once all like sensors have been calibrated, they can be removed from the sonde and installed in other sondes. The sensor will retain its calibration. Required calibration frequency will be determined during the wetland demonstration.

Industrial $H_2S$ gas detectors will be used at the HWTT and VWTT. The detectors include local indication of $H_2S$ gas measurement. These detectors will be mounted on two-inch diameter poles so that they can be raised or lowered easily, as necessary.

The $H_2S$ detectors have disposable battery packs; the manufacturer recommends changing the packs on a quarterly basis. The application of solar panels is under consideration as a feature of the wetland demonstration.

The $H_2S$ detector requires calibration involving a $H_2S$ span gas and associated safety equipment. The recommended calibration frequency is monthly to quarterly. Calibration data will be collected during the wetland demonstration to determine the minimum calibration frequency needed for a full-scale system.

The selected wireless $H_2S$ detectors are durable and made to withstand harsh outdoor environments. The wireless technology was chosen to minimize conduit runs and so that the sensors could be moved to find the best locations without adding difficult infrastructure. This flexibility was necessary since the exact location of the highest $H_2S$ gas concentrations is unknown at this time. The wireless technology also allows for easy addition or subtraction of detectors.

## 3 Network Communication Equipment

The purpose of telemetry in the wetland demonstration is to prove that the selected approach will work for a full-scale system. The server and its connecting network can be reused for a full-scale system.

Various hardware components will integrate digital signals from different instrumentation. The data will be proven useful where it is stored on a server located in the existing Former Lime Treatment Plant Building, accessible onsite or remotely. Operators will practice with the CLEARscada interface while viewing contemporaneous data. The data will easily be examined via the internet.

### 3.1 Network Instrument Communication

Instrumentation data will be transmitted to the server by the following methods, as pictured on design drawing sheet E-2, Telemetry / Network.

Signals transmitted by the electromagnetic flow meters will be processed by the SCADApack controller SP-1 via direct connection of analog and pulse signal wires. These are not digital type signals and thus are not included with the network diagram.

Multiple sonde signals will be combined with YSI's serial modules. Then each serial module will send a serial digital signal to the data logger. The signals will be converted to Modbus in the data logger and sent to SCADApack SP-1.

The $H_2S$ detectors have 2.4 GHz frequency radio Modbus output. This is the only wireless communication in the network. Each sensor will be equipped with its own antenna for sending signals. A radio receiver with an antenna installed at Control Junction Box 1 will create a network of the $H_2S$ detectors. The detectors act as repeaters, and each detector will channel the signal from other detectors to the radio receiver in a 'mesh network.' The receiver will send the data from all the $H_2S$ detectors to SCADApack controller SP-2 via hard wire Modbus cable.

### 3.2 Network Communication Hardware

Interface with the sonde Modbus information and with the $H_2S$ detector Modbus information will be accomplished by separate controllers, SCADApack SP-1 and SCADApack SP-2, respectively. Therefore, the programming of the controllers relative to the two sources of Modbus information will be kept separate.

An Ethernet switch will be used to combine signals from the two SCADApack controllers. Data will be transmitted to the PC server for storage and remote access.

The selected PLC, the SCADAPack 350, will communicate with the PC server. It can accept alarm and setpoint changes from the PC server while sending the monitoring data to the PC server.

A PC desktop computer server will be located in the Former Lime Treatment Plant Building and will receive and store the incoming data from the network. Data may be accessed while on site in the Former Lime Treatment Plant Building or remotely off site. Users will be required to log in with a username and password to gain access to the system. Different user levels will control access to the network.

### 3.3 Telemetry Selection Rationale

The SCADAPack 350 was selected for its low power demands, which facilitate use with solar power in remote locations; its ability to integrate radio, cellular, and/or a satellite networks; the ability to accept multiple types of connections, such as analog, digital, and Modbus; and its PLC features to control, log, and monitor data collection instruments. The SCADApack 350 will be used to transmit and manipulate signals from the sensors site wide.

CLEARscada interface software was selected because its database capabilities are conducive to large-scale data collection activities. It also facilitates communication with multiple servers, which enables future expansion of the telemetry system. The CLEARscada software will be hosted on the PC desktop server in the Former Lime Treatment Plant Building.

## 4 Operational and Health, Safety, Security, & Environment Benefits

Telemetry will allow operators to evaluate site conditions before they arrive, which will minimize the amount of time spent on site identifying/diagnosing operational problems. Site personnel will be better able to anticipate maintenance events, such as instrument calibration, by analyzing contemporaneous data, as opposed to extrapolating from previous field events. Telemetry records will improve system operator efficiency, and remote data acquisition will reduce the number and duration of field visits.

Alarm features will notify operators of a release to the environment or if unsafe conditions exist. The difference in flow rates between influent and effluent for a given treatment train will have an allowable tolerance. If the tolerance is exceeded, the system will notify an operator that inlet flow is not accounted for by the outlet flow reading. Such a release of water could occur with freezing or system clogging.

The turbidity exiting the settling basins will be monitored, and operators will be notified of increasing trends that could adversely impact performance of the HWTT and VWTT.

Static head monitoring with pressure transducers within Agridrain compartments will document the manual stoplog heights selected by the operator. Agridrain stoplogs will be used to maintain the unit process water levels. The treatment train flow rates and hydraulic conductivities will determine the stoplog heights needed.

The $H_2S$ detectors will allow operators to review concentrations prior to performing activities near $H_2S$ exclusion zones at the HWTT aeration channel and VWTT aeration cascade. The $H_2S$ detectors will have established alarm limits that, if exceeded, will warn operators.